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Fundamental Characteristics Of Jet Propulsion Engines

M. J. ZUCROW

Purdue University

From the day when the Wright Brothers flew at Kitty Hawk in 1902 until World War II, the reciprocating internal combustion engine, or piston engine, driving a propeller was the only propulsion system available to the aircraft designer. During the elapsed period of more than 50 years, the piston engine-propeller system was developed to a remarkable degree of reliability for so complicatd a mechanism. The specific weight of the engine was lowered to approximately 1.1 pounds of dry weight per rated horsepower, and its fuel consumption reduced to approximately 0.5 pound per horsepower-hour. Despite these excellent accomplishments, the piston engine is not destined to play any significant role in the propulsion of aircraft flying at speeds above 450 miles per hour.

The objects of this paper are:

(1) to point out why the piston-engine propeller system is inadequate for the propulsion of high speed aircraft; and
(2) to discuss the fundamental characteristics of jet propulsion engines.

Power Required for Level Flight.—The horsepower which must be imparted to an airplane to maintain it in level, unaccelerated, flight is called the *thrust horsepower* P_T, and is given by:

$$P_T = \frac{FV}{375} = \frac{DV}{375} = \frac{\sigma V^3 C_D S}{146{,}000} \qquad (1)$$

where

$\sigma = \dfrac{\rho}{\rho_0}$ = density ratio

ρ_0 = density of atmospheric air at sea level = 0.002378 slug/ft.^{3}

ρ = density of the atmosphere at altitude, slug/ft.^{3}

V = true air speed, miles per hour.

C_D = drag coefficient = $391\ D/\rho V^2 S$

D = drag of airplane, lb.

S = projected wing area, sq. ft.

F = thrust, lb.

Editor's Note: We are pleased to present this invited article by M. J. Zucrow, Professor of Gas Turbines and Jet Propulsion, Purdue University, Lafayette, Ind.

Equation 1 shows that if the drag coefficient C_D remains constant then the required thrust horsepower at a given altitude increases as the cube of the flight speed. Actually, the drag coefficient remains substantially constant only at relatively low flight speeds where the motion of a body through the air may be analyzed by incompressible fluid flow theory which assumes that the density of the air is constant. If the flight speed, usually expressed in terms of Mach number M, is increased until it attains a certain critical value, which depends on the wing section and its planform, the density of the air can no longer be assumed to be a constant and the drag coefficient increases rapidly due to compressibility effects.[1] For modern aircraft the free stream critical Mach number where compressibility effects are first experienced has a value close to $M = 0.7$. At sea level this corresponds to a flight speed of 535 miles per hour and to 465 miles per hour at 40,000 ft. altitude. Figure 1 illustrates the rapid increase in the drag coefficient with flight Mach number for two airfoil sections. It is seen that the deleterious effects of compressibility occur at a higher flight Mach number for the thinner airfoil section (NACA 0012) indicating that the wings of high speed aircraft should be thin. The increase in the drag coefficient is due to the formation of shock waves on the upper surface of the airfoil; the air flowing over the upper surface is accelerated to velocities higher than the flight speed, and at high flight speed attain the velocity of sound.

If the speed of the airfoil is increased further, the shock waves move toward the leading edge, causing the flowing air to separate from the surface of the airfoil. When fully developed supersonic flow is established, at approximately $M = 1.3$ for modern airfoils, a bow shock wave is formed in front of the leading edge of the airfoil and a tail wave downstream to its trailing edge. A further increase in speed does not affect the pattern of the flow around the airfoil. The drag coefficient tends to decrease, and flow conditions tend to become stable.

Figure 1 also presents an estimate of the variation of the drag coefficient with Mach number for an airplane of the Gloster Meteor type. The curve shows that in the range $M = 0.6$ to $M = 1$ the drag coefficient is increased fourfold (Hooker, 1946). At $M = 2.0$ the value of C_D drops to twice its value at $M = 0.6$. The foregoing discussion demonstrates that at high flight speeds the thrust power for propelling an airplane increases substantially faster than the cube of the flight speed.

By way of illustration, consider the effect of flight speed on the power requirements for a single seater fighter which requires a piston engine developing 1200 hp. to attain a flight speed of 300 miles per hour at sea level. If it is assumed that the propeller efficiency is 0.8, the corresponding thrust horsepower is 960 hp. Assuming a constant propeller efficiency and neglecting compressibility affects, then, to attain a flight speed of 550 miles per hour, the thrust horsepower required is 5900 thp. and at 600 miles per hour, it becomes 770 thp. In the actual case, the

[1] Flight Mach number is the ratio of the true airspeed to the acoustic velocity in the atmospheric air.

affects of compressibility on the airframe will cause the drag coefficient to increase rapidly at speeds above 520 miles per hour. At 550 miles per hour, for example, the required thrust horsepowers will increase to about 6800 hp., and at 600 miles per hour, to approximately 12,000 hp. Neglecting the effect of compressibility on the propeller blades and assuming a constant propeller efficiency of 0.8 the size of the piston engine required is 8500 hp. at 550 miles per hour, and 15,000 hp. at 600 miles per hour. The actual piston engine power required will be even greater because the effects of the compressibility of the air on the propeller blade tips reduces the propeller efficiency.

Because of the aforementioned compressibility effects upon both the airframe and propeller, extremely large piston engine power outputs are required for high speed flight. It is the aforementioned characteristics of the piston engine-propeller propulsion that made it imperative to develop the newer jet propulsion engines for achieving high flight speeds.

Definition of Jet Propulsion.—Jet propulsion has at times been termed reaction propulsion. This is a misnomer, however, because all methods for propelling a body through a fluid are based on the reaction principle. Jet propulsion differs from other methods of propulsion (e.g., propeller propulsion) in that in jet propulsion, the propulsive fluid is ejected from within the propelled body in the form of a jet.

Classification of Jet Propulsion Engines.—In the abstract, at least, there are no restrictions upon the physical and chemical characteristics of the working fluid which is to be ejected as a high speed fluid jet from a jet propulsion engine. When it comes to the propulsion of bodies through the air of the atmosphere, however, the practicalities of the propulsion problems encountered limit the choice of the appropriate working fluids. Excluding the possibilities of atomic energy, experience demonstrates that only two methods for producing the high speed fluid jet are suitable for the propulsion of bodies through the atmosphere.

First, there is the high speed fluid jet produced by compressing atmospheric air, heating it by burning a fuel in it, and then discharging the resulting hot gases to the atmosphere as a high speed jet, by expanding them in a suitable exhaust nozzle. A fluid jet produced in the aforementioned manner will be termed a *thermal jet*, and the apparatus or engine for producing such a jet will be called a *thermal jet engine;* the ramjet and turbo-jet engines are thermal jet engines.

Second, suitable chemicals, usually an oxidizing agent and fuel, both being carried within the propelled body, can be caused to react chemically and produce high temperature, high pressure gases which are then expanded in a suitable nozzle and ejected to the surroundings as a high speed fluid jet. For example, the oxidizing agent might be liquid oxygen and the fuel might be an alcohol. Each chemical is called a *propellant*. A jet produced by expanding the high pressure, high temperature gases produced by the chemical reaction of such propellants, both carried within the propelled body, is called a *rocket jet*. The assembly of components for producing the rocket jet is called a rocket engine.

Jet propulsion engines may, therefore, be grouped into two broad classes:

(a) thermal jet engines, and

(b) rocket engines.

Classification of Thermal Jet Engines.—Thermal jet engines may be segregated into the following three principal types (Zucrow ,1948):

(a) the Ramjet Engine or Athodyd (Aero-Thermo-Dynamic-Duct);

(b) the Pulsejet Engine; and

(c) the Turbojet Engine.

Combinations of the principal types of thermal jet engines are possible and also their combinations with the rocket engine. The discussion will here be confined to the principal types of engines.

The Ramjet Engine—Figure 2 illustrates the essential features of the ramjet engine. It comprises a diffuser section; a combustion chamber section; and an exhaust nozzle section. The function of the diffuser is to decelerate the air entering the engine and to give an efficient transformation of its kinetic energy into a pressure rise, called the *ram* pressure. The ram pressure rise obtained will be a function of the flight speed, the inlet and diffuser design, and the area ratio of the diffuser.

In operation, the air compressed in the diffuser flows into the combustion chamber, which contains the fuel burners, and is heated to a high temperature by the continuous combustion of fuel. Although liquid fuels are most generally used, the Germans conducted limited experiments with solid fuels. The highly heated gases produced in the combustion chamber are then expanded in the exhaust nozzle and finally ejected to the atmosphere with a velocity exceedingly that of the entering air. Because of the increase in the momentum flux entering and leaving the ramjet engine, a reaction force or thrust is developed in the direction of flight. It is fairly evident that the performance of the ramjet engine will be affected by its flight speed.

Since the operation and performance of the ramjet depends upon "building up" the ram pressure of the entering air, the engine cannot function at zero flight speed. To make it operative, the body propelled by the ramjet engine must be given an initial velocity by some auxiliary means. Because it is an "air-burning" engine, the maximum operating altitude of the ramjet is limited. The ramjet is inherently a device which performs best at very high speeds, and is potentially a power plant for attaining supersonic flight speeds. The origin of the ramjet is credited to the Frenchman, Lorin, 1913.

The propulsion characteristics of the ramjet engine indicate that it has excellent potentialities as a propulsion engine for achieving supersonic flight, especially for propelling certain types of supersonic guided missiles. Since combustion considerations necessitate reducing the free stream supersonic air velocities ($M > 1$) to a relatively low subsonic value ($M = 0.2$) at the entrance to the combustion chamber, the deceleration of the free

stream air at the inlet to the engine is accompanied by the formation of shock waves at the inlet, with the result that the entropy of the fluid entering the engine is increased above its free stream value, and energy losses, whic hcan be serious, are introduced. Studies of the characteristics

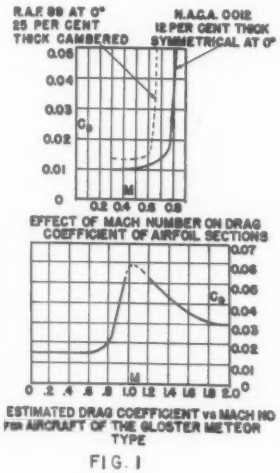
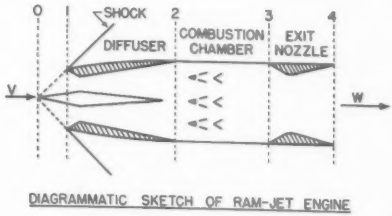
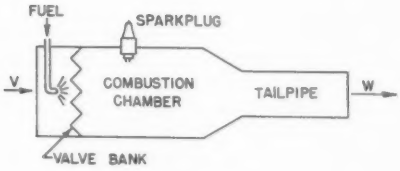


FIG. 1



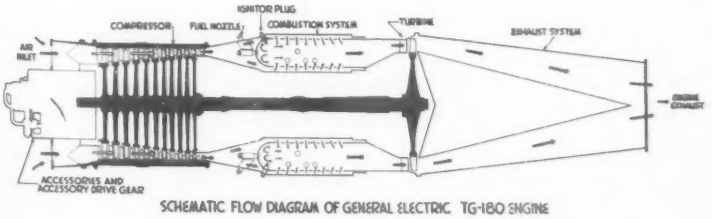
DIAGRAMMATIC SKETCH OF RAM-JET ENGINE

FIG. 2



PULSEJET ENGINE

FIG. 3



SCHEMATIC FLOW DIAGRAM OF GENERAL ELECTRIC TG-180 ENGINE

FIG. 4

Fig. 1—Effect of Mach Number on Drag Coefficient of Airfoil Section. Estimated Drag Coefficient vs. Mach No. for Aircraft of the Gloster Meteor Type.

Fig. 2.—Diagrammatic Sketch of Ram-Jet Engine.

Fig. 3.—Pulsejet Engine.

Fig. 4.—Schematic Flow Diagram of General Electric TG 180 Engine.

of air flow through a ramjet engine without combustion, conducted by the National Advisory Committee for Aeronautics, indicate that by appropriate design, the energy losses attendant to decelerating a supersonic stream of air to subsonic velocities can be minimized so that the actual ram pressure recovery will be a significant fraction of that theoretically available.

Considerable research effort must be expended to obtain information on basic phenomena occurring in ramjet engines. For example, one major problem is that of securing stable combustion in a velocity air stream at low absolute pressure, and the effect of combustion pulsations upon the shock waves formed at the entrance to the engine. Experiments have demonstrated that the interaction between the combustion pulsations and the shock waves at the engine entrance can cause the actual performance of a ramjet engine to fall considerably below that possible theoretically. The combustion problem is aggravated at high altitudes, due to the low absolute pressures in the combustion chamber. Considerable research in the field of subatmospheric burning at high air velocities is needed to provide information for extending the operating altitude of the ramjet engine. Other problems are aerodynamic in character and the background for solving them requires an extension of the scope of our present knowledge.

The Pulsejet Engine.—This engine is illustrated schematically in Figure 3. It comprises an inlet diffuser, a combustion chamber, and a valve bank through which air can flow in the direction of the tail pipe. When closed, the valves prevent any reverse flow of gases from the tail pipe to the entrance. Fuel injection nozzles are generally placed upstream to the valve bank, and an electric spark plug is located in the combustion chamber. The valves operate as shutters that open against their own spring pressure (Edelman, 1946; Morris, 1952.)

In flight, combustion air is forced into the engine by the ram pressure, and the fuel is supplied continuously. The resulting fuel-air mixture is ignited initially by the electric spark plug, but once the engine is in operation, no auxiliary ignition is required. The pressure rise due to combustion causes the valves to close, and the combustion gases are discharged through the tail pipe with a velocity greater than that of the entering air. The net result is a thrust in the direction of flight. (Edelman, 1946; Morris, 1952.)

The ejection of the gases reduces the pressure in the combustion chamber to a value below that of the atmosphere. The reduction in pressure combined with the ram pressure acting on the valves cause the latter to reopen, and a new cycle commences.

The pressure in the combustion chamber varies in a cyclic manner, the operating cycle repeating itself with a frequency that depends upon the physical dimensions of the unit. In the case of the German V-1 missile, commonly called the buzz-bomb, the firings occurred at an approximate rate of 40 per second. Pulsejet engines of smaller size, with 250 to 300 firings per second, have been built.

From an overall point of view, the pulsejet engine may be regarded as being an intermittent firing ramjet engine, and the thrust it develops

is proportional to the average values of the mass rate of flow of air times its increase in velocity. In the ideal case, the combustion process would be isovolumic, but in the actual case, because of the finite combustion time and the escape of gases through the tailpipe, the combustion process deviates considerably from the isovolumic process.

Like the ramjet engine, the thrust of the pulsejet engine increases with the flight speed, and its maximum operating altitude is limited by air density considerations. Unlike the ramjet, however, it develops thrust at zero speed, but a high initial launching velocity improves its performance.

Currently, there is no exact theory of operation for the pulsejet engine and that has probably hampered its development. It is generally believed, however, that aerodynamic conditions at the inlet limit its maximum flight speed to less than 600 miles per hour. The flight speed of the ramjet engine, on the other hand, appears to be limited by the aerodynamic heating effects of the outer skin, to speeds of the order of 2000 miles per hour. The pulsejet is a simple, cheap engine for subsonic flight and is well adapted to subsonic pilotless aircraft such as the German V-1 missile.

The first use of the pulsejet principle is credited to Karavodine of France (1906). The modern conception of the pulsejet engine is, however, due to the German, Paul Schmidt, who began his development of this engine in 1928 (Edelman, 1946).

The Turbojet Engine (*The Gas Turbine Jet Engine*).—This engine is currently the most important type of jet propulsion engine for aircraft propulsion. Figure 4 illustrates schematically the principal features of an axial flow turbojet engine, which is essentially a continuous combustion gas turbine. The air entering the engine is partially compressed in the diffuser and then compressed to a much higher pressure by either a centrifugal or an axial flow air compressor. The highly compressed air is then heated by the combustion of fuel in a combustion chamber to a temperature of 1500° to 1600° F.; the maximum allowable temperature is limited by metallurgical and stress considerations. The combustion takes place at sensibly constant pressure. The highly heated air, containing approximately 2 per cent of combustion products, then expands through a turbine which is directly connected to the air compressor and furnishes the power for driving the air compressor. The gases are discharged from the turbine with a pressure higher than that of the atmosphere, and with a temperature ranging from 900° to 1300° F. From the turbine the gases pass through a tailpipe and are finally expanded and ejected to the atmosphere through a suitably shaped nozzle at the rear of the unit. The ejection velocity of the gases is greater than the air entrance velocity.

Figure 5 is a cross-section through a Rolls Royce turbojet engine which utilizes a centrifugal compressor, a single stage turbine, and nine atomizing-type combustors.

Like the ramjet engine, the turbojet engine is a continuous flow engine. It has the advantage over the ramjet engine in that it dos not depend upon the ram pressure of the entering air for its operation. The amount of

ram pressure recovered does, however, affect its overall economy and performance.

Fig. 5.—Cross Section of Rolls Royce Turbojet.

Although all of the thermal jet engines discussed have been investigated experimentally in either military aircraft or guided missiles, only the turbojet engine has been applied as the sole propulsion means for piloted aircraft. It appears to be eminently suited for propelling aircraft at speeds above 500 miles per hour, at least in the subsonic range. As the flight speed is increased still further, the ram pressure increases rapidly, and characteristics of the turbojet engine tend to change over to those of the ramjet engine. Consequently, its top speed is limited to that flight regime where it is more advantageous to use the ramjet engine. No reliable figures can be given at this time, but estimates indicate that for speeds above approximately 1200 miles per hour it will be more advantageous to use the ramjet engine.

The modern conception of the turbojet engine can be traced to a patent issued to Guillaume of France in 1922. The patent discloses the use of a gas turbine to drive an axial flow air compressor. The first reduction to practice must be credited, however, to Air Commodore Frank Whittle of England who filed his first patent on January 11, 1930. At that time, air compressors were too inefficient, the permissible operating temperatures for turbine blades were too low, and the speeds of aircraft were much

too slow to make jet propulsion attractive. His tenacity and faith in the turbojet engine were rewarded in 1937 when his first operating engine was developed. The first flight was conducted with a Gloster airplane in May 1941, and the Welland series of engines based on Whittle's designs were put into production in 1944.

In Germany, the studies of the turbojet engine were initiated as far back as 1930, and the Germans were the first to fly an airplane propelled by a turbojet engine (August 27, 1939). (Neville, 1948).

As in the case of any gas turbine power-plant, the efficiencies of the components of the turbojet engine have an influence on its performance characteristics (Streid, 1946). The performance of the turbojet engine, however, is not nearly so sensitive to changes in the efficiency of its component machines as is a gas turbine which delivers shaft power.

Turbojet propelled fighter aircraft are currently flying at speeds of approximately 650 miles per hour, and jet propelled bombers having speed capabilities of 550 to 650 miles per hour are a distinct possibility (Hage, 1948). If one judges the future by the present trends, turbojet propelled transports with speeds of 525 miles per hour are a distinct possibility in the very near future. It is reasonable to assume that once the reliability of the turbojet engine has been established, so that a 500 hour span between major overhauls can be secured, and the problems of airport traffic control for high speed aircraft have been solved, the application of the turbojet engine propulsion to commercial transport will follow rapidly. The operating experience being obtained currently with the De Haviland Comet, a jet propelled commercial aircraft, will be of great value to the future development of jet propelled commercial aircraft.

The major research problems pertinent to further development of the turbojet engine are those which must be solved to obtain the following:

(a) more efficient, higher pressure ratio, higher flow capacity, smaller, and lighter air compressors;

(b) more efficient and reliable turbines capable of operating at higher inlet temperatures; and

(c) stable combustion over a wider range of operating conditions.

It is not possible in this paper to discuss all of these problems in detail, but some brief comments will be presented concerning some of the phases of current research.

It has been mentioned that two types of compressors are currently employed, the centrifugal compressor and the axial flow compressor. Irrespective of the type, the objectives are similar. The compressor must be reliable, compact, easy to manufacture, and have a small frontal area.

The centrifugal compressor has the advantage of simplicity, reliability, ease of manufacture, and high pressure ratio per stage, while the axial flow compressor has a higher stage efficiency and a smaller frontal area for a given flow capacity.

The centrifugal compressor development is hampered by the lack of an adequate theory and basic data on the flow of air through its passages. Also, it is difficult to maintain both high efficiency and high pressure ratio with either a single stage or by multi-staging. In the interests of a reasonable air compression efficiency the centrifugal turbojet engine has been restricted to employing a single stage compressor thus limiting its maximum pressure ratio of 4.5 to 1 approximately. Another drawback of the centrifugal compressor is that its flow capacity is limited by the shock phenomena of the compressor entrance. Current research is directed to obtaining a more accurate knowledge of the flow processes and means for overcoming the problems just presented.

Current axial flow compressor research is directed to increasing the pressure ratio per stage with the object of reducing the length and cost of the machine. At this time, the maximum pressure ratio per stage is approximately 1.15 to 1, but the results of research indicate that much higher pressure ratios per stage should be achievable (possibly as high as 2 or 3 to 1). In this same connection, investigations are being conducted to obtain fundamental information regarding the possibility of employing supersonic flow in the rotating blades and utilizing weak shock waves to aid in compressing the air.

Turbine research is concerned with means for reducing losses, means for cooling the blades to permit the use of higher inlet temperatures, and ways for supplanting the present construction materials (principally chrome, nickel, and cobalt alloys) with nonstrategic materials. In a turbojet engine, and also in a gas turbine which delivers shaft power, the temperature limitations are imposed by the blade materials. Currently, about 66% of the air flowing through the engine is used as a coolant to reduce the temperature of the combustion gases from their temperature of 3500° F. to a temperature permissible for the turbine blades. Current research is concerned with various methods of air or liquid cooling of the blades, the possibility of using ceramic blades, and the properties of sintered blades synthesized from nonstrategic materials. The material for turbine blades must be capable of withstanding thermal shock and oxidation at high temperatures. The National Advisory Committee for Aeronautics has devoted considerable effort to the development and investigation of materials made by sintering ceramic-metal combinations (termed ceramels) by methods similar to those used in the powdered metallurgy field. Some promising results have been obtained.

The turbojet engine, because of its rather flat thrust versus speed curve, introduces certain operational problems at take-off due to the small ratio of take-off thrust to thrust in flight. Since the exhaust gases from the turbine contain considerable excess air, the possibility of increasing the jet velocity by burning additional fuel in the tailpipe upstream to the exhaust nozzle is being investigated. Figure 6 illustrates the types of results being obtained. It is seen that "tailpipe burning" can increase the thrust at take-off by 35%, and at 500 miles per hour, by approximately 60%. The value of this additional thrust in a military operation is obvious.

The Rocket Engine.—Rocket propellants may be either liquids or solids. A rocket engine using a liquid oxidizing agent and a liquid fuel to produce high pressure, high temperature gases, is termed a bipropellant liquid rocket engine. One employing solid chemicals is termed a solid propellant rocket engine. Due to space limitations the subsequent discussions will be limited to bipropellant liquid rocket engines.

The functioning of a rocket motor differs basically from that of a thermal jet engine in two major respects:

(1) it does not use atmospheric air; and

(2) its thrust depends entirely upon the effective velocity of the exhaust jet, and does not depend upon a momentum difference as is the case for either a thermal jet engine or a propeller.

Because the thrust of a rocket motor depends only upon the effective jet velocity, denoted by w_{eff}, it is unaffected by the speed at which the propelled body travels if the propellant consumption rate is held constant.

The particular advantages of rocket jet propulsion may be summarized as follows:

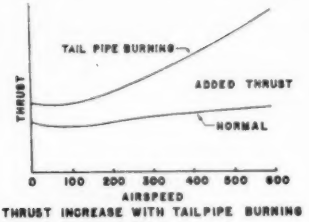
1. its thrust is independent of its speed;
2. its thrust is practically independent of its environment;
3. it has no altitude ceiling since it does not require atmospheric oxygen for its operation;
4. it functions best in a vacuum; and
5. its thrust per unit of frontal area is the largest of any known propulsion engine.

It is the above advantages which stimulated the pioneers in the field of rocketry, because they saw that the rocket possessed the potentialities for attaining extreme altitudes and speeds, and for making escape from the earth and even space travel technical possibilities.

The aforementioned advantages of rocket jet propulsion result from the fact that the rocket propelled body carries its own oxidizer as well as its fuel. This, however, is a mixed advantage. Because the oxygen for burning the fuel is not taken from the atmosphere, the rate at which a rocket engine consumes propellants (oxidizer plus fuel) is several times the rate at which a thermal jet engine consumes fuel, the only combustion component carried in the thermal jet propelled body or vehicle.

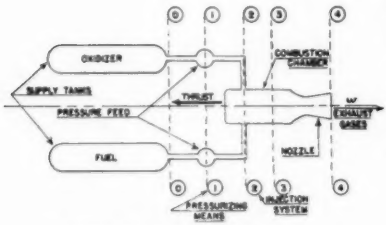
To illustrate, a rocket engine developing 10,000 lb. thrust will consume approximately 45 lb. of propellants per second, while a turbojet engine developing 10,000 lb. thrust at sea level will consume only 2.8 lb. of fuel approximately in the same length of time. Because of its enormous rate of propellant consumption the operating time of a rocket, called its *powered flight*, is extremely short. For example, the powered flight of the German V-2 missile was 67 sec and that for the Viking Sounding Rocket 75 sec.[2]

[2] "Advance Man to the Moon," Aero. Digest, October, 1951, p. 26.



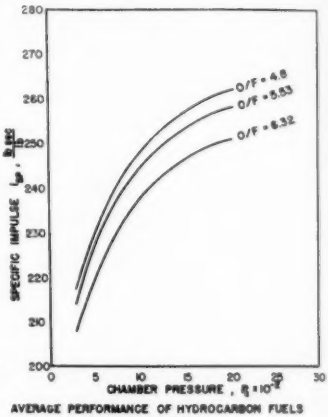
THRUST INCREASE WITH TAILPIPE BURNING

FIG. 6



ELEMENTS OF LIQUID ROCKET SYSTEM

FIG. 7



AVERAGE PERFORMANCE OF HYDROCARBON FUELS OXIDIZED BY WFNA

FIG. 8

Fig. 6.—Thrust Increase with Tailpipe Burning.

Fig. 7.—Elements of Liquid Rocket System.

Fig. 8.—Average Performance of Hydrocarbon Fuels Oxidized by WFNA.

The enormous rate of propellant consumption limits the endurance of a rocket propelled airplane, and consequently its range, to small values. For a rocket propelled vehicle to achieve a large range, the vehicle must be propelled so that it has large velocity and a high altitude at the end of the *powered flight*. The large kinetic energy of the vehicle is then utilized to achieve range by coasting; that is, it must have a ballistic type of trajectory. To obtain the required velocity at the end of powered flight a large thrust must be imparted to the vehicle for a relatively short time, a minute or two.

The large thrust per unit area developed by the rocket engine and the fact that its thrust is more or less independent of the altitude does, however, give a rocket propelled airplane a decided performance advantage.

Figure 7 illustrates the essential features of a bipropellant liquid rocket motor. It comprises an injector, a combustion chamber, a DeLaval exhaust nozzle, and propellant control valves. In addition it is equipped with a regenerative cooling system for keeping the walls exposed to the high temperature gases at a safe operating temperature; one of the propellants is circulated around the combustion chamber and nozzle before being injected into the combustion chamber.

The rate of flow of the propellants into the combustion chamber and the mixture ratio (oxidizer weight rate of flow/fuel weight rate of flow) are governed by the areas of the respective injection orifices and the differential pressures acting upon them. The pressure of the combustion gases depends upon the throat area of the exhaust nozzle. The combustion gases are ejected to the atmosphere with supersonic velocity, with speeds ranging from 6,000 to 11,000 feet per sec., depending upon the propellant combination. The combustion pressures generally range from 300 to 800 psia (pounds per square inch, absolute).

The performance of a rocket propellant combination is expressed in terms of either its specific impulse I_{sp}, the impulse obtained from reacting one pound of the propellant combination, or its effective exhaust velocity w_{eff}. If F denotes the thrust, G_p the rate of propellant consumption, and g the gravitational acceleration, then

$$w_{eff} = \frac{gF}{G_p} = gI_{sp} \tag{2}$$

If the thermodynamic properties of the combustion gases are either known or estimated from thermo-chemical calculations, the specific impulse can be calculated. Otherwise it must be determined by experiment.

One of the most potent common propellant combinations is liquid oxygen-liquid hydrogen, which gives an exhaust velocity of 10,800 feet per sec. This is a difficult combination to handle in practice. Liquid oxygen boils at −190° C. and liquid hydrogen boils at −252° C., making the storage problem exceedingly difficult; moreover, liquid hydrogen manufacturing facilities are practically unavailable. More widely used combinations are liquid oxygen-alcohol, and nitric acid in combination with a variety of fuels. The search for better and more potent propellants continues, and investigations in the propellant field have been concerned with materials varying from powdered metals to fluorine and its derivatives. Unfortunately the results obtained so far are not too encouraging in the hope of finding a chemical propellant combination having a specific impulse significantly larger than that obtainable from the liquid oxygen-liquid hydrogen combination (335 sec.).

The specific impulse of a rocket propellant combination can be increased by reacting the propellants at higher combustion pressures than are normally utilized. Figure 8 presents the calculated values of the specific impulse for white fuming nitric acid (WFNA) reacted with hydrocarbon fuels at different combustion pressures, and different oxidizer fuel ratio by weight (Trent, *et al.*, 1949).

The operation of rocket motors with either higher energy propellants or at high combustion pressures leads to very high rates of heat transfer to the metal walls if they are to be maintained at a safe operating temperature. An appreciation of the heat transfer problem can be obtained from

Table I which presents measured values of the heat transfer rates for rocket motors burning white fuming nitric acid (WFNA) and jet engine fuel (JP-3) at 300, 500, and 700 psi combustion pressure (Zucrow and Beighley, 1952).

Table I.

MEASURED VALUES OF THE MAXIMUM HEAT TRANSFER RATES FOR WFNA AND JP-3

(Obtained from three different rocket motors each designed for 500-lb. thrust and $L^* = 100$ in.)

Heat transfer rates in B.t.u. per sq. in. per sec.

MEASURED VALUES

Combustion pressure (psia)	Thrust cylinder q_c	Ratio, $\frac{q_c}{(q_c)_{300}}$	Nozzle q_n	Ratio, $\frac{q_n}{(q_n)_{300}}$	Rocket motor q_o	Ratio, $\frac{q_o}{(q_o)_{300}}$
300	1.3	1.00	2.8	1.00	1.7	1.00
500	2.2	1.69	4.0	1.43	2.6	1.53
700	2.3	1.77	6.0	2.14	3.5	2.06

It should be noted that the overall heat transfer rate for the nozzle at 700 psia combustion pressure was 6.00 B.t.u. per sq. in. per sec. (3×10^6 B.t.u. per sq. ft. per hr.). That value is considerably below the peak value which occurs at the throat, which is difficult to measure. Estimates indicate that the peak value at the throat is probably twice the overall for the nozzle.

It was pointed out earlier in this paper that to achieve a long range the rocket propelled vehicle must follow some form of ballistic trajectory. The question of the best trajectory and the best programming of the thrust has been studied by several investigators, and that type of investigation needs continuing effort. One of the major problems is the proper programming of the angle of attack of the rocket propelled vehicle as is re-enters the atmosphere after descending from an extreme altitude. Since the velocity of the vehicle at re-entry will be practically the same as that which it had on leaving the atmosphere, some means for reducing its speed is necessary, so that its skin will not become overheated and a safe landing speed can be achieved. Calculations by H. S. Tsien (ARS, 1 Dec. 1949) on a 3000 mile range rocket propelled vehicle show that these objectives are not at all beyond the grasp of present day technology.

World War II witnessed the development and application of a variety of rocket weapons. The incentives for developing them were the small weight of rocket launchers, compared to artillery pieces, for large-caliber projectiles, the freedom of the rocket launcher from recoil, and the need for equipping infantrymen and military aircraft with light-weight large-

caliber weapons. Furthermore, the possibilities of the rocket as the propulsion plant for long range missiles were demonstrated by the German V-2 rocket-propelled missile. The Germans also demonstrated the possibilities of the rocket as a propulsion system for extremely fast intercepter aircraft, the ME 163 airplane, propelled by a liquid-propellant rocket power plant.

Rocket developments in the United States during World War II were concerned primarily with their application as infantry and aircraft weapons, as jet-assisted take-off (JATO) units for aircraft, and for superperformance of aircraft at high altitudes. Both liquid and solid propellant rocket engines were employed for those applications.

Since World War II rocket jet propulsion has been applied to guided missiles, for launching ramjet engines, and as a research tool in aeronautics. In the latter connection, rockets have been applied to the propulsion of aerodynamic models in free flight, for obtaining data on aerodynamic forces and control-surface effectiveness, and to the propulsion of such research aircraft as the Bell X-series and the Douglas D-558 series, for obtaining quantitative data on drag, stability, air loads, etc., at supersonic flight speeds. The rocket has also been employed for propelling sounding rockets, such as the Viking, for obtaining data on the properties of the upper atmosphere.

Despite its apparent simplicity, the development of reliable rocket power plants having good performance characteristics (a satisfactory thrust/weight ratio) requires solving a large number of perplexing problems. The complete rocket system must be light in weight, and the rocket motor must be capable of sustained operation with gases at temperatures higher than 5000° F. flowing through it. Many of the propellants utilized in liquid propellant rocket power plants are extremely corrosive which introduces major material problems. Furtheromer, owing to the enormous energy releases, high gas pressures, and high gas temperatures, problems of rapid ignition of the propellants, smooth start-up, stable combustion, precise control of the oxidizer/fuel ratio under accelerating and angle of attack conditions, thrust control, adequate cooling, material selection, and several others are encountered. In the case of turbo-pump pressurized rocket engines there are problems pertinent to the development of extremely light-weight high-speed (16,000 to 30,000 revolutions per minute) rotary machines of large capacity, with their cavitation, sealing, and bearing problems. In addition, the development of light-weight high-temperature gas generators, for driving the turbine, introduces system control and material problems.

Conclusions.—Jet propulsion engines, whether of the thermal jet or rocket jet types, should not be regarded as competitors of the piston engine-propeller propulsion system in the low and moderate flight speed range. They are power plants for realizing objectives which are unattainable with the piston engine propeller drive. When the propulsion of aircraft at speeds significantly faster than 450 miles per hour is being considered, jet propulsion engines, such as the turbojet, the ramjet, and the rocket,

are the only engines that possess the capabilities of realizing such objectives. The turbojet is in current use as the propulsion plant for military high speed subsonic aircraft. For short duration supersonic flight at extreme altitudes, for extremely fast climbing intercepter aircraft, for jet assisted take-off, and guided missile propulsion, the rocket engine has demonstrated its potentialities.

At present, the power plant field related to the propulsion of bodies through the air at extremely high speeds is in a state of flux. Several promising power plants are available for attaining different objectives. Intensive development of these newer engines and their combinations are in progress, and the era of truly highly speed flight is on the horizon.

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Characters of Systematic Importance in The Family Branchiobdellidae (Oligochaeta)[1]

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Recent morphological and systematic studies have revealed hitherto unsuspected relationships between genera of the Branchiobdellidae and indicated the importance of variations in the internal anatomy as features of systematic significance. This paper is concerned with an evaluation of systematic characters.

Previous works with similar aims are meager. Hall (1914) considers the external form, preoral lobe, the structure of the dental plates, and the structure of the genitalia as systematic characters. Ellis (1919) discusses the dentition, the pharyngeal diverticula, and the "buttress-like supports of the intersegmental partitions" as features of systematic importance. In a previous work (1912) he took into account the number of the anterior nephridiopores and the structure of the male reproductive system. Yamaguchi (1934) states that Pierantoni (1912) attached much importance to the "ventral cirri", dorsal appendages of the trunk, the form of the peristomium, the structure of the dental plates, and the number of pairs of testes and male funnels. Yamaguchi himself discusses the dorsal appendages and ridges, the peristomium, and the "pharyngeal diverticula". Goodnight (1940) evaluates the systematic importance of the following characters: body shape, dorsal appendages, peristomium, jaws and dentition, position of the caudal sucker, shape of the gut, pharyngeal diverticula, opening of the anterior nephridia, number of testes, accessory sperm tube, penis, and shape of the spermatheca.

There follows a brief review of these and some other characters in the light of the studies mentioned above.

1. *Body shape.*—The flattened bodies of *Xironodrilus* and *Xironogiton* are distinctive and set these two genera sharply apart from all other genera of branchiobdellids. The tapering body of *Xironodrilus* is distinct from the "tennis racket" shape of *Xironogiton*.

2. *Dorsal appendages.*—Excluding the Japanese forms, the genera *Pterodrilus* and *Cirrodrilus* are readily separable from the remaining American genera by possessing dorsal appendages, and the variations in the appendages are of specific value in *Pterodrilus*. Whether *Cirrodrilus* can be separated from *Pterodrilus* is doubtful. Not available to me until recently, specimens of *Cirrodrilus thysanosomus* (Hall) appear to have many other features in common with the species of *Pterodrilus* in addition to the presence of dorsal appendages that resemble those of *Pterodrilus alcicornis*. The raised annuli of certain species of *Cambarincola* (e. g., *C.*

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chirocephala) approach the dorsal appendages of *Pterodrilus* and present even more of a problem than *Cirrodrilus*, since it is only by means of the dorsal appendages that *Pterodrilus* and *Cambarincola* can be separated. Nonetheless the varying forms of the dorsal appendages are useful characters of specific value and are the only ones that can be utilized in separating the genera *Pterodrilus* and *Cambarincola*.

3. *Peristomium.*—As pointed out by Ellis (1919), Yamaguchi (1934), and Goodnight (1940) the plurilobate, or better, the tentaculated, peristomium occurs in such diverse genera as *Branchiobdella*, *Stephanodrilus*, and *Cambarincola*, and is of no generic value. There may be some differences, however, in the arrangement of the tentacles associated with other generic characters. In *Cirrodrilus*, for instance, there are four dorsal tentacles that flare, and a lateral tentacle on each side of the mouth, while among those species of *Cambarincola* possessing tentacles, there are four dorsal tentacles that are shorter, do not flare so noticeably, and the lateral tentacles are absent.

4. *Jaws.*—The significance of the number of teeth borne by the jaws of the branchiobdellids is a vexing problem. Ellis (1919) has attempted to classify the types of jaws and devised a system for expressing the dental formula by means of capital letters for the larger teeth and lower case letters for the smaller ones. It is my feeling that the shape of the jaws should be considered along with the number of the teeth and that dental formulae, atlhough usable, are not solely to be relied upon in the diagnosis of species.

5. *Position of the caudal sucker.*—Considered a generic character by Goodnight, the ventral suckers of *Xironodrilus* and *Xironogiton* are a consequence of the depressed body form of these genera and are considered along with this character as an additional feature that separates these genera from the remaining ones which belong to the family.

6. *Shape of the gut.*—The shape of the gut does change with the amount of contained food and the degree of contraction of the body, but the expansions of the gut seem to occur in a characteristic fashion in certain segments in given groups of species; for instance, the expansions of the gut in segments II, III, and IV, with sharp constrictions between these expansions, and with the gut proceeding along a straight course to the anus is a characteristic of the genus *Xironodrilus*. Goodnight's view that the shape of the gut is of only dubious specific value is, therefore, rejected.

7. *Pharyngeal diverticula.*—Ellis (1919) in a search for characters of taxonomic significance was impressed with the "pharyngeal diverticula". These "diverticula" are encircling folds of the pharyngeal wall and are permanent structures determined by the manner of attachment of the radial dilator muscles of the pharynx. There are two of these folds in the pharyngeal wall, but the posterior one is often obscured by the degree of contraction of the animal. Since they appear to be commonly found throughout the family, being present in essentially the same form in all of the species of the five genera that I have investigated, they are of no diagnostic significance.

8. *The manner of opening of the anterior nephridia.*—The common opening of the anterior nephridia through a bladder-like dilatation which opens to the outside by a mid-dorsal pore on segment III is characteristic of a group of genera. Difficult to detect in ordinary preparations, and hence of no great practical value as a diagnostic character, the manner of opening of the anterior nephridia may be of considerable value in evaluating the relationships between groups of genera.

9. *The male reproductive system.*— —

a. The number of testes — Not having had an opportunity to study the genus *Branchiobdella*, which is characterized by the possession of only one pair of testes in segment V, I can say nothing in regard to the use of this character by Goodnight (1940) in dividing the family into the subfamilies Branchiobdellinae and Cambarincolinae. Certainly such a variation in the reproductive system is of considerable value in separating groups of branchiobdellids.

b. Spermatic vesicle — Practically all previous workers have mentioned the organ that is here called the spermatic vesicle; however, only Moore (1894, 1895), and more recently Holt (1949), among American workers, have described this organ with any degree of consistency and accuracy, and Moore failed to do so in the case of *Pterodrilus alcicornis*. The only exception to this statement is Ellis' (1912) figure of *Cambarincola macrodonta*. This confusion has usually been associated with a failure to understand the proper relationship of the accessory sperm tube to the spermatic vesicle. That the variations that may occur in the shape and proportions of the spermatic vesicle are of systematic importance is illustrated by the species of *Xironodrilus*.

c. Accessory sperm tube — I have shown previously that this structure is not to be confused with the blindly ending proximal portion of the spermatic vesicle of *Xironogiton* (Holt, 1949), and more recently (in ms.) the existence of the accessory sperm tube has been demonstrated for the first time in *Pterodrilus*. The presence or absence of this feature of the male reproductive system is of generic value and the degree to which it is separated from the spermatic vesicle and its relative size is of specific value.

d. Ejaculatory duct — The presence or absence of an ejaculatory duct is of specific value in the genus *Xironodrilus*. In all other genera that I have studied it is present, but its relative proportions vary, and these variations may be of specific significance.

e. Bursa — In the genera *Pterodrilus* and *Cambarincola* the relative size and shape of the bursa is useful in distinguishing the several species belonging to them, and it seems probable that the same may be true for separating the species of the genus *Xironogiton*.

f. Penis — The eversibility or non-eversibility of the penis has been considered as of generic value by Goodnight (1940), but there are species of *Cambarincola* (the genus cited by Goodnight as having non-

eversible penes) with eversible penes (Holt, in mss.). Thus this character cannot be accorded generic distinction, but it is a useful one in diagnosing certain species.

10. *The female reproductive system.* — —

a. Spermatheca — The shape of the spermatheca is of specific value in some groups (e. g., *Pterodrilus*), while in others there may be a wide range of intraspecific variability in this organ (e. g., *Xironodrilus pulcherrimus*). The bifid character of the spermatheca of *Bdellodrilus illuminatus* has been considered a generic character.

11. *Glands.*—The lateral glands present in the nine postcephalic segments of *Bdellodrilus illuminatus* are undoubtedly of systematic importance. The lateral "adhesive organs, "located on segments VIII and IX of members of the genus *Xironodrilus*, have been considered of generic importance (Goodnight). It should be pointed out, however, that Ellis (1919) described "glandular adhesive disks" for *Xironogiton occidentalis*, but the assignment of this species to the genus *Xironogiton* is suspect. The greatly flared, lateral portions of segments V to VIII of the other species of *Xironogiton* are glandular and a critical evaluation of the "adhesive" organs in the closely related genera is impossible at present.

SUMMARY

Of the characters described above, the "pharyngeal diverticula" are of no diagnostic value. The shape of the body, the dorsal appendages, the general shape of the jaws, the position of the caudal sucker, the shape of the gut, the manner of opening of the anterior nephridia, the number of pairs of testes, the presence or absence of the accessory sperm tube, the bifid spermatheca, and the presence of lateral glands are of generic importance.

Variations in the dorsal appendages, the tentaculated peristomium and its variations, to a limited extent variations in the shape of the jaws and the number of teeth, the shape and proportions of the spermatic vesicle, the proportions of the accessory sperm tube, the presence and proportions of the ejaculatory duct, the relative size and shape of the bursa, the eversibility of the penis, and the shape of the spermatheca are of specific value.

These studies emphasize the necessity for making careful studies of the internal anatomy of the branchiobdellids. Only in this way can accurate systematic work be done. Formerly the genera *Xironogiton* and *Cambarincola* were considered to possess the accessory sperm tube in common. Actually these two genera are far removed from each other in the subfamily Cambarincolinae and the accessory sperm tube is absent in species of *Xironogiton*. On the other hand Moore's reference to the "cleft atrium" of *Pterodrilus* has been overlooked, along with the relationship of this genus to *Cambarincola*.

I am confident that many new species of branchiobdellids will be recognized as closer attention is paid to the features discussed above, particularly the variations that occur in the male reproductive system.

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The Chromosomes of the Polygyrid Snail *Allogona profunda*[1]

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The family Polygyridae is the most widely spread group of helicid snails in North America. Four of the genera of the family are known in Virginia: *Stenotrema*, *Mesodon*, *Triodopsis*, and *Allogona*. In an earlier report (Husted and Burch, 1946) the chromosomes of eighteen species and subspecies of the first three of these were described and discussed in some detail. We are now concerned with the fourth genus, *Allogona*.

Allogona is represented by three species. One, *A. profunda*, is found in the Ohio valley and eastward, in the upper and middle Mississippi and lower Missouri valleys. It extends as far west as Nebraska and Kansas and a little farther north. Two species, *A. townsendiana* and *A. ptychophora*, are separated by approximately 800 miles from *A. profunda* and found west of the continental divide in Montana, Idaho, Oregon, Washington, and British Columbia (Pilsbry, 1940).

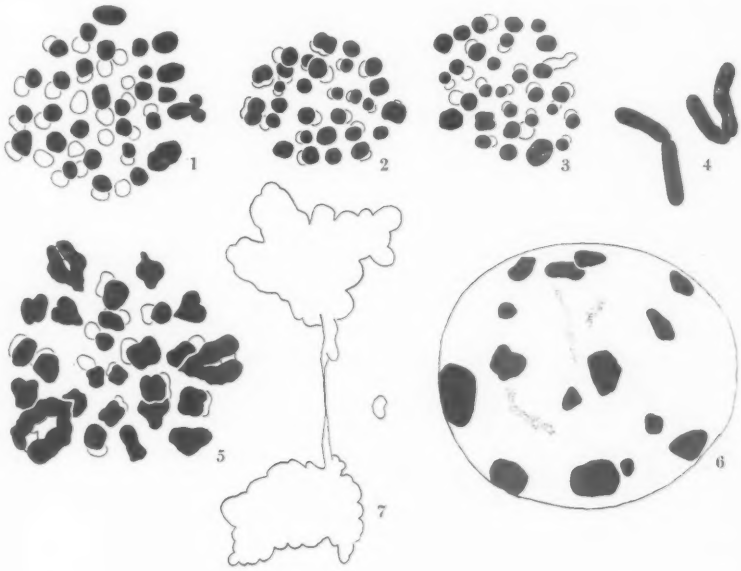
According to Pilsbry, this primitive genus is characterized chiefly "by the possession of a strongly developed stimulator in the penis, – a structure not known in any other Polygyridae, – and an epiphallus with vestigial concealed flagellum. Except that the penial sheath is mainly or wholly adnate to the penis, the organization is otherwise about as in Triodopsis."

We have examined two individuals of *A. profunda* found on Wolf Creek in Giles County, Virginia. They had epiphragms over their apertures when collected and were fed in a humid aquarium for one week before the ovotestes were prepared for study. The method of fixing and staining described by Husted and Burch, (*l. c.*) was followed. These differ cytologically from the other Virginia genera of the family in three ways: the chromosomes are larger, fewer in number, and spermatogonial nuclei contain chromosomes which in certain regions at least are conspicuously heterochromatic.

The largest chromosomes of *Stenotrema*, *Mesodon*, and *Triodopsis* at metaphase I (Figs. 1-3) are only slightly larger than the smallest found in *A. profunda* (Fig. 5). At metaphase of the last spermatogonial mitosis

[1] The cost of collecting this material was partly defrayed by a grant from the Virginia Academy of Science.

the largest *profunda* chromosomes (Fig. 4) are nearly 8 micra in length while comparable chromosomes in the other genera are less than 5.



EXPLANATION OF FIGURES.—The chromosomes of four species of Polygyridae. *Fig.* 1. *Stenotrema monedon aliciae.* Fig. 2. *Mesodon rugeli.* *Fig.* 3. *Triodopsis tridentata edentilabris.* *Fig.* 4. Two of the largest chromosomes of *Allogona profunda* at mitotic metaphase. *Fig.* 5. *Allogona profunda*, twenty-six bivalents. Fig. 6. Spermatogonial nucleus showing heterochromatin and a small portion of the euchromatin. *Fig.* 7. *A. profunda*, bridge and fragment, Anaphase I. X2651.

The chromosome number of species of *Stenotrema*, *Mesodon*, and *Triodopsis* found in southwestern Virginia is characteristically 58. *Mesodon appressus* has 58 chromosomes in Virginia but is known in New Jersey with 62. *Triodopsis fraudulenta* may have 58, 59, 60, or 62 chromosomes. These supernumerary chromosomes resemble the others of the complement in behavior and, as far as can be determined, in structure. The two individuals of *Allogona* we have analyzed have 52 chromosomes, 6 less than are found in the "more highly evolved" relatives that have been examined. These chromosomes are regular in their behavior forming 26 bivalents at meiosis (Fig. 5). They are uniformly and intensely stained

by the Feulgen reaction at meiotic metaphase I. In spermatogonial cells at rest or in prophase, however, numerous deeply stained masses differentiated from the less deeply stained euchromatin occur (Fig. 6). These heterochromatic regions, which were not seen in *Stenotrema*, *Mesodon* and *Triodopsis*, appear at prophase to occupy interstitial and terminal portions of certain chromosomes in both spermatogonia and oocytes.

In one individual evidence for structural hybridity is found in cells at anaphase I (Fig. 7). The chromatid bridges, each accompanied by a fragment, are the first encountered in a thorough examination of 129 polygyrid snails.

The chromosomes of all the genera of the Polygyridae in Virginia are now known. The "primitive" *A. profunda* with 52 chromosomes, or 6 less than the related species in this region, is in agreement with our earlier suggestion that the gradual increase in chromosome number characteristic of the pulmonata, and demonstrated in *Triodopsis fraudulenta*, may be attributed to the duplication of chromosomes one or two at a time. In this connection a study of the west coast species of *Allogona* would be of interest.

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Note on Egg-laying of the Four-toed Salamander, *Hemidactylium scutatum* (Schlegel), in Eastern Virginia

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A recent survey (Wood, 1951) provides information on the nesting of the Four-toed Salamander, *Hemidactylium scutatum* (Schlegel), in Virginia. The egg-laying period for this species was reported to extend from February 24 to March 10, 1951 (Wood, ibid.; Wood and Wilkinson, 1952). Additional information on the nesting of this species was obtained on a field trip on February 17, 1952 to a branch pond located one-half mile southeast of Harpersville, Warwick (formerly Warwick Co.), Virginia. Five groups of adults were found along the margin of the pond in Sphagnum hummocks surrounded by water. The number of adults in each group, and the number of eggs present, were as follows:

GROUP NUMBER	1	2	3	4	5
NUMBER OF ADULTS	2	3	2	3	1
NUMBER OF EGGS	–	150	–	145	34

All of the adults were females with full or spent ovaries. This observation at the beginning of the egg-laying period is evidence that gregarious nesting occurs as early as nesting occurs, and is not the result of lack of suitable discrete habitats in which nests can be placed. It is also evidence that females will deposit their eggs in nests containing the eggs of other females while the earlier nesting females are still in attendance. No competition between the gravid females and those with spent ovaries has resulted in the driving of the latter away from the nests. Noble (1930) has suggested that in the case of the Marbled Salamander, *Ambystoma opacum* (Gravenhorst), exhaustion accounts for the female remaining with her eggs. No assay of the extent of exhaustion following the egg-deposition of these females was attempted, but it was noted that when disturbed they sought refuge by quickly scrambling into the adjacent water. They did not appear to retreat more slowly than is usual in this species when specimens are encountered in habitats other than nesting sites under similar conditions of temperature.

[1] Box 534, Williamsburg, Virginia.

Of particular interest was the observation that most of the eggs in each of the egg groups were submerged. The finding of submerged *Hemidactylium* eggs has not been reported previously in the literature, although Wood (ibid.) found that submerged eggs will develop into larvae in this species. The moss hummocks in which the eggs were found were surrounded by water, and were located a few inches from the shore. The authors did not interpret these sites as permanent insular locations because it is entirely possible that heavy rainfall on the previous night raised the water level enough to isolate the hummocks from the shore and submerge most of the egg masses. Females have never been observed depositing eggs under water, and the females attending these partially submerged nests were not in the water when first observed.

LITERATURE CITED

NOBLE, G. K. 1930. Probing life's mysteries. *Nat. Hist. Mag., Amer. Mus. Nat. Hist.*, 30 (5): 469-82.

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WOOD, J. T. AND R. H. WILKINSON. 1952. Observations on the egg masses of Spotted Salamanders, *Ambystoma maculatum* (Shaw), in the Williamsburg area. *Va. Jour. Sci.* (*N. S.*), 3 (1): 68-70.

News and Notes

(Editor's note: News contributions should be sent to the person whose name appears at the end of the appropriate section.)

SECTION NEWS

BACTERIOLOGY SECTION

The Virginia Branch of the Society of Americal Bacteriologists held a meeting in the Department of Microbiology, University of Virginia, on Saturday, December 6, 1952. The following is an outline of the program of the meeting.

11:00 A.M. — Business Meeting.

12:00 Noon — Luncheon.

2:00 P. M. — Scientific Session.

A Study of Dogs as Vectors of Salmonella in the Area of Richmond, Virginia.

William Paul Bennett; *Department of Biology, University of Richmond.*

Rice Products in the Cultivation of *Endamoeba histolytica.*

E. Clifford Nelson and Muriel M. Jones;*Department of Bacteriology and Parasitology, Medical College of Virginia.*

Beneficial Effects of Egg White in Viral Complement Fixation Tests. (*and*) Techniques for Making Permanent Reading Standards for the Determination of Total Proteins in Spinal Fluid Specimens.

C. A. Crooks, Jr.; *City Health Department, Richmond.*

A Microcolony Technique for the Rapid Determination of Bacterial Sensitivity to Antibiotics.

H. J. Welshimer, Muriel M. Jones, and C. D. Gibson, Jr.; *Departments of Bacteriology and Parasitology, and Medicine, Medical College of Virginia.* — J. DOUGLAS REID, *R.F.D.* 13, *Richmond.*

BIOLOGY SECTION

The Department of Biology of the University of Virginia has a three section greenhouse, 85 x 25 feet in size, now under construction. Associated with the greenhouse is a building which will provide additional laboratory space, and quarters in which birds and mammals for research use in Parasitology, Physiology, and Genetics will be housed. New laboratories are also being equipped for work in General Physiology, Plant Physiology, and Morphogenesis.

Mr. D. W. Bierhorst, Instructor in Botany, University of Minnesota, has been appointed Assistant Professor of Biology at the University of Virginia, effective September 1953. He will offer courses in Evolution, Plant Ana-

tomy, and Morphogenesis to graduate and advanced undergraduate students.

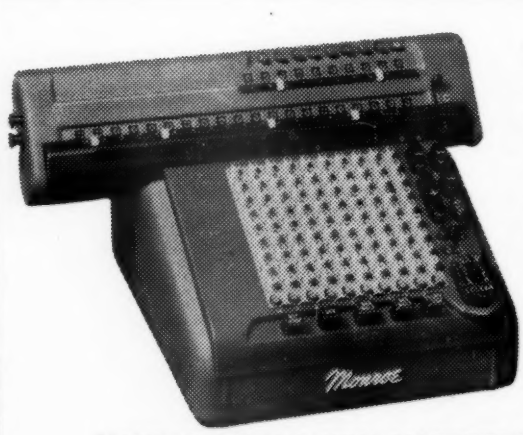
The Conservation Committee of the Academy (J. J. Shomon, Chairman) appeared before the State Board of Education on Thursday, February 26, to appeal for the re-establishment of the position of Conservation Counselor with the State Department of Education.

Another conservation item of interest is the recent organization of a Virginia Resource-Use Education Council, composed of representatives from State and Federal agencies. The function of the Council is to promote and correlate the various efforts of conservation education throughout the State. The secretary of the council is R. R. Bowers, Commission of Game and Inland Fisheries, 7 North Second Street, Richmond.

J. T. Baldwin, Jr. of the College of William and Mary is editing a popular book on the Dismal Swamp. It is sponsored by the Virginia Academy of Science and is being written by Mr. Baldwin and ten collaborators.

Miss Particia Casey, a 1952 graduate of Mary Baldwin College, is now a technician in the Laboratory of Hematology in the City-County Hospital in Dallas, Texas.

Another Mary Baldwin graduate, Miss Janet Russell, is employed in the histology laboratories of the Sloan-Kettering Institute for Cancer Research in New York City. — ROBERT T. BRUMFIELD, *Longwood College.*



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STATISTICS SECTION

A brochure on the Department of Statistics and the Statistical Laboratory of the Virginia Polytechnic Institute has been prepared and is available for distribution. This brochure explains courses of study offered in the Department of Statistics as well as the research and consultation of the Statistical Laboratory.

Paul Somerville of the Institute of Statistics, University of North Carolina, and W. J. Youden of the National Bureau of Standards, spoke at graduate colloquia at Virginia Polytechnic Institute.

An all-day conference on statistics and I. B. M. procedures was held at Virginia Polytechnic Institute on Wednesday, March 4, 1953. R. A. Bradley spoke on "Some Uses of I. B. M. Equipment in Statistics" and Boyd Harshbarger spoke on "Statistics at Virginia Polytechnic Institute."

C. Y. Kramer has completed work for his Master of Science degree in statistics at Virginia Polytechnic Institute.

The Department of Statistics at Virginia Polytechnic Institute is conducting a study for the State Highway Department, Commonwealth of Virginia, on certain matters relating to highways.

Boyd Harshbarger presented an invited address, "Some Lattice Designs", as the seventh lecture of a series of lectures sponsored by the Departmental Committee on Experimental Design and the Agricultural Research Administration, in the Department of Agriculture Auditorium, Washington, D. C., and at the Bureau of Plant Industry, Beltsville, Maryland.

The following papers have been published by members of the Virginia Polytechnic Institute Statistics Department:

1. The Estimation of Parameters from Sequentially Sampled Data on a Discrete Distribution, by M. C. K. Tweedie. The Journal of the Royal Statistical Society, Series B (Methodological), Vol. XIV, No. 2, 1952.
2. The Rank Analysis of Incomplete Block Designs I—The Method of Paired Comparisons, by Ralph A. Bradley and M. E. Terry. Biometrika 39, 1952.

Reprints of the above papers are available.

R. A. Bradley is chairman of the Eastern Regional Program Committee, Institute of Mathematical Statistics. The following are members of the Program Committee, Biometric Society (Eastern North American Region): Boyd Harshbarger, (chairman), and Alonzo Myster.

The next eastern regional joint meeting of these societies will be held in the South Building of Agriculture, Washington, D. C., April 29, 30, and May 1. — W. A. HENDRICKS.

NOTES

Through errors the following abstracts of papers presented at the Thirtieth Annual Meeting of the Academy at Old Point Comfort, May 16, 1952, were not included in the Proceedings (Va. Jour. Sci., N. S., 3 (4), 1952).

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A Means Whereby Bacteria-Free Inocula of *Histomonas meleagridis* may be Obtained.

Arthur P. Harrison, Jr. and P. Arne Hansen; *Department of Bacteriology and the Livestock Sanitary Service Laboratory, University of Maryland, College Park.*

The lives of 24 turkeys which died of infectious enterohepatitis (blackhead) were sampled and 17 found to contain bacteria. On the other hand, of the livers from 36 turkeys sacrificed at the first appearance of symptoms, only 12 yielded bacteria. The discovery that early in the disease a high proportion of the livers from birds having blackhead are bacteria-free provides a useful method of acquiring *Histomonas meleagridis* inocula free of contaminating bacteria. Hence, it becomes feasible to experiment with pure cultures of the histomonad furnishing further evidence of the etiological role of this protozoon in blackhead disease.

The method used to acquire bacteria-free inocula of *Histomonas meleagridis* consists merely of sacrificing poults at the first appearance of symptoms and aseptically macerating their livers. The resulting liver suspension may be used in experiments which require *Histomonas meleagridis* inocula, but paralleling these experiments a portion of the suspension is tested for bacterial sterility as follows: A few mls. from the initial dilution are added to tubes of turkey serum – Ringer's solution-rice starch medium. In addition, aerobic EMB and anaerobic Eugonagar pour plates are prepared. Incubation is for two days at 41° C.

Cell Division in the Epidermis of the Foetuses and Young Lambs of Karakul Sheep.

Lubow A. Margolena and Ethel H. Dolnick; *Animal Fiber Laboratory, Bureau of Animal Industry, U. S. Department of Agriculture.*

Growth of hair follicles and their fibers depend on the proliferation of the original epidermal cells. Hence, foetal and lamb skins of Karakul sheep were observed with particular attention to follicular development and mitoses in the epidermal cells. Skin samples were taken immediately following death. The animals were sacrificed between 9:00 and 11:00 A.M. Fixation was in Bouin's solution; final dehydration in butyl alcohol; sections were cut about 10 microns thick; and staining was by two haematoxylin procedures, a connective tissue stain, and Feulgen's reaction.

Counts were made of no less than 5000 nuclei of epidermal cells per sample from 20 foetuses ranging from 45 to 147 days (full gestation in sheep being about 150 days). Data on lamb skins of 16 animals, varying in age from one to 30 days, were collected in similar manner. All figures were expressed in percent of mitotic nuclei to total metabolic nuclei. Our mitotic counts are relatively low, yet they show a trend sufficiently clear to state that, both in the dorsal and ventral epidermis, mitotic activity is about 10 times as great just prior to and during the very early hair anlage as compared to the period of rapid proliferation and differentiation of the follicular cells. This intense follicular development

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falls within 90 ot 100 days of intro-uterine life. Data show that mitoses in the epidermal cells of the ages examined never reach the high peak of the immediate pre-follicular stage.

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OF THE

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General Program of the Thirty-First Annual Meeting 1953

VIRGINIA MILITARY INSTITUTE

LEXINGTON, VIRGINIA

WEDNESDAY, MAY 6

3:00 P.M. to 8:00 P.M. – Registration for Junior Academy members, participants in the Science Talent Search, Academy members, and guests, Room 354, Mallory Hall.

3:00 P.M. to 8:00 P.M. – Setting up Exhibits: Commercial, Rooms 335, 341, Mallory Hall; Free, Room 359, Mallory Hall; Junior Academy, Rooms 435, 441, 459, Mallory Hall.

THURSDAY, MAY 7

8:00 A.M. to 8:00 P.M. – Registration for Junior and Senior Academy members and guests, Room 354, Mallory Hall.

9:00 A.M. – Meeting of Science Exhibit Judges; Room 434, Mallory Hall.

9:30 A.M. – Meeting of chairman and exhibitors; Room 434, Mallory Hall.

10:00 A.M. to 12:30 P.M. and 1:30 P.M. to 4:00 P.M. – Finalists of Talent Search meet with Chairman and interviewers; Rooms 434, 442, 454, 242, 249, 252, Mallory Hall.

10:00 A.M. to 12:30 P.M., 1:30 P.M. to 4:00 P.M. – Judging of Science Exhibit Contests; Rooms 45, 441, 459, Mallory Hall.

3:00 P.M. – Meeting of the Talent Search Committee; Room 434, Mallory Hall.

3:30 P.M. – Meeting of all Senior Academy Section Officers; Room 257, Mallory Hall.

4:00 P.M. – Meeting of the Section Editors, Room 237, Mallory Hall.

4:30 P.M. – Regimental Parade, Parade Ground.

5:00 P.M. – Senior Academy Conference and General Meeting; Room 111, Mallory Hall.

7:30 P.M. to 8:30 P.M. – Business meeting, Junior Academy of Science; Auditorium, Preston Library.

8:30 P.M. — General Electric "House of Magic" for Junior Academy members and guests; Jackson Memorial Hall.

FRIDAY, MAY 8

8:00 A.M. to 6:00 P.M. — Registration; Room 354, Mallory Hall.

9:00 A.M. — Section Meetings: Agricultural Sciences, Room 234, Mallory Hall; Astronomy, Mathematics, Physics, Room 111, Mallory Hall; Bacteriology, Room 44, Mallory Hall; Biology, Room 147, Mallory Hall; Chemistry, Room 102, Maury-Brooke Hall; Education, Room 454, Mallory Hall; Engineering, Room 105, Nichols Engineering Hall; Geology, Room 249, Mallory Hall; Medical Science, Room 442, Mallory Hall; Psychology, Room 18, Scott-Shipp Hall; Science Teachers, Room 252, Mallory Hall; Statistics, Room 237, Mallory Hall.

10:30 A.M. — Presentation of awards, Junior Academy; student presentation of exhibits. Address by John C. Fisher, Metallurgy Research Department, General Electric Company, Auditorium, Preston Library.

12:30 P.M. — Group Luncheons.

2:00 P.M. — Section Meetings.

3:30 P.M. to 4:45 P.M. — Symposium "Resource Use Education", sponsored by Virginia Resources Use Education Council, Lecture, Old Science Hall. (See program of Section of Biology.)

4:30 P.M. to 6:00 P.M. — Superintendent's Reception for members and guests of the Academy; Alumni Hall.

7:30 P.M. — Business Meeting, Senior Academy, Room 147, Mallory Hall.

8:30 P.M. — Address by Professor Hubert N. Alyea, Frick Chemistry Laboratory, Princeton University, "ATOMIC ENERGY: WEAPON FOR PEACE."

SATURDAY, MAY 9

9:00 A.M. — Section Meetings.

10:00 A.M. — Academy Council Meetings; Room 631, Preston Library.

2:00 P.M. — Field trips.

Small group luncheons or dinners may be arranged by writing Colonel R. P. Carroll, Department of Biology, Virginia Military Institute, Lexington, Virginia.

Program of
Virginia Junior Academy of Science

WEDNESDAY, MAY 6

3:00 P.M. to 8:00 P.M. – Registration for Junior Academy members, participants in the Science Talent Search.

3:00 P.M. to 8:00 P.M. – Setting up Exhibits.

THURSDAY, MAY 7

8:00 A.M. to 6:00 P.M. – Registration for Juniors.

9:00 A.M. – Meeting of Science Exhibit Judges.

9:30 A.M. – Meeting of Chairman and Exhibitors.

10:00 A.M. to 12:30 P.M. – Finalists of Talent Search meet with Chairman and Interviewers.

10:00 A.M. to 12:30 P.M. – Judging of Science Exhibit Contests.

1:30 to 4:00 P.M. – Continuation of Interviews of Finalists.

1:30 to 4:00 P.M. – Continuation of Judging of Exhibit Contests.

3:00 P.M. – Meeting of the Talent Search Committee.

5:30 P.M. – Dinner meeting of Junior Academy Committee.

7:30 P.M. – Business meeting of the Junior Academy of Science.

8:30 P.M. – General Electric "House of Magic" Show.

FRIDAY, MAY 8

10:30 A.M. – Student Presentation of Selected Exhibits. Address by John C. Fisher, Metallurgy Research Department, General Electric Company. Presentation of Junior Academy Awards.

3:30 P.M. – (For those Juniors still in attendance) Symposium, "Resource Use Education", sponsored by Virginia Resources Use Education Council. (See program of Section of Biology.)

8:30 P.M. – (For those Juniors still in attendance). Address by Dr. Hubert N. Alyea, Frick Chemistry Laboratory, Princeton University, "ATOMIC ENERGY: WEAPON FOR PEACE".

Section of Agricultural Sciences

T. J. NUGENT, *Chairman*
H. MARSHALL CLARK, *Vice-Chairman*
RODNEY C. BERRY, *Secretary*
WESLEY P. JUDKINS, *Section Editor* (1956)

FRIDAY, MAY 8, 1953 – 9:00 A.M. – ROOM 234, MALLORY HALL

9:00 Announcements, Committee appointments, etc.

1. 9:15 Insecticides – Research.
D. E. Greenwood; *Virginia Truck Experiment Station.*

2. 9:45 Insecticides – Regulatory Laws.
J. Claggett Jones; *Virginia Department of Agriculture.*

3. 10:15 Control of Mites in Strawberries in Virginia.
R. N. Hofmaster and D. E. Greenwood; *Virginia Truck Experiment Station.*

4. 10:30 Effect of Variety on the Ascorbic Acid on Carotene Contents and on the Yield of Sweet Potatoes.
James F. Eheart, P. H. Massey, Jr. and R. W. Young; *Virginia Agricultural Experiment Station.*

5. 10:45 The Effect of Light, Soil pH, and Trace Elements on the Carotene, Thiamine and Riboflavin Contents of Turnip Greens.
P. H. Massey, Jr., James F. Eheart and R. W. Young; *Virginia Agricultural Experiment Station.*

6. 11:00 Trace Element Studies of Some Virginia Pasture Plants.
Nelson O. Price and W. N. Linkous; *Virginia Agricultural Experiment Station.*

7. 11:15 A Suggested Role for Agricultural Scientists in Mineral Prospecting.
Richard V. Dietrich; *Virginia Polytechnic Institute.*

FRIDAY, MAY 8, 1953 – 1:30 P.M.

8. 1:30 The Relationship Between Size and Efficiency of Feed Utilization in Beef Cattle.
James E. Grizzle; *Virginia Agricultural Experiment Station.*

9. 1:45 Silage Studies.
Paul M. Reaves and R. Emory Brubaker; *Virginia Agricultural Experiment Station.*

10. 2:00 Types Studies for Proving Bulls.
Paul M. Reaves and Max Lund; *Virginia Agricultural Experiment Station.*

11. 2:15 The Evaluation of Stress in Dairy Cattle.
G. C. Graf; *Virginia Agricultural Experiment Station.*

12. 2:30 A Study of New Modified Babcock Tests.
C. C. Flora and G. E. Fisher; *Virginia Agricultural Experiment Station.*

13. 2:45 Information Which Can be Obtained in a Short Time From Long-Time Cropping and Fertilizer Experiments.
Russell K. Stivers; *Virginia Agricultural Experiment Station.*

14. 3:00 A Picturesque Trip Through the Dismal Swamp of Virginia.
Elvin F. Henry; *Virginia Agricultural Experiment Station.*

3:15 Business Meeting.

Section of
Astronomy, Mathematics, and Physics

S. M. HEFLIN, *Chairman*
L. W. WEBB, JR., *Secretary*
I. G. FOSTER, *Section Editor* (1956)

FRIDAY, MAY 8, 1953 – 10:00 A.M. – ROOM 111, MALLORY HALL

1. 10:00 A New Theory of Convergence.
E. J. McShane; *University of Virginia.*

2. 10:15 On the Embedding of a Sequence of Closed Sets in a Sequence of Arcs.
B. J. Ball; *University of Virginia.*

3. 10:30 Inelastic Scattering of 2.5 Mev Neutrons.
R. E. Garrett, F. L. Hereford, and B. W. Sloope; *University of Virginia.*

4. 10:45 General Equation for Conics and Pseudoconics.
Richard E. Herron and D. S. Davis; *Virginia Polytechnic Institute.*

5. 11:00 Pictures in Polars.
J. L. Troutman, J. M. Reynolds, and D. S. Davis; *Virginia Polytechnic Institute.*

6. 11:15 Lens Aberrations – Demonstration and Experiment.
I. G. Foster; *Virginia Military Institute.*

7. 11:30 A Lecture or Undergraduate Laboratory Experiment Demonstrating Both Temperature Coefficient of Resistance and the Fourth Power Radiation Law.
M. E. Cruser and E. C. Stevenson; *University of Virginia.*

8. 11:45 The Energy Loss of Mu-mesons and Electrons in Sodium Iodide.
G. M. Snead and S. J. Stratis; *University of Virginia.*

FRIDAY, MAY 8, 1953 – 2:00 P.M.

2:00 Business Meeting.

9. 2:15 Teaching Physics as a Profession.
S. M. Heflin; *Virginia Military Institute.*

10. 2:30 Tensile Strength of Thin Metallic Films.
Harold S. Morton; *University of Virginia.*

11. 2:45 The Equilibrium Ultracentrifuge.
Andrew Robeson and Norman Snidow; *University of Virginia.*

12. 3:00 The Magnetic Suspension Balance.
Walter E. Lotz, Jr., *University of Virginia.*

13. 3:15 The Measurement of Magnetic Fields.
Robert T. Wagner; *University of Virginia.*

14. 3:30 Gyro-magnetic Ratios.
Glen S. Waterman, C. J. Davisson, and J. W. Beams; *University of Virginia.*

SATURDAY, MAY 9, 1953 – 9:00 A.M.

15. 9:00 Magnetic Suspension Circuits.
Joseph Swingle, *University of Virginia.*

16. 9:15 Double Ultracentrifuge Cell.
Henry M. Dixon and J. W. Beams; *University of Virginia.*

17. 9:30 Ferromagnetic Deflection of High Energy Electrons.
S. Berko and F. L. Hereford; *University of Virginia.*

18. 9:45 The Polarization of Annihilation Quanta and the Einstein, Podolsky, Rosen Experiment.
F. L. Hereford and S. Berko; *University of Virginia.*

19. 10:00 Some Proposed Experiments with Liquid Helium.
J. W. Beams; *University of Virginia.*

20. 10:15 A Simple Method for the Measurement of the Surface Temperature of Rapidly Rotating Bodies.
A. R. Kuhlthau and E. M. Foley; *University of Virginia.*

21. 10:30 Astrometric Orbit of Gamma Geminorum.
Harold L. Alden and V. Osvalds; *University of Virginia.*

22. 10:45 Population Groups among Stars of Spectral Type G.
A. N. Vyssotsky; *University of Virginia.*

23. 11:00 Effect of Contamination on Transmission and Reflection of Light by Thin Metal Films.
H. Y. Loh and Peter Cheo; *Department of Physics, Virginia Polytechnic Institute.*

Section of Bacteriology

W. FRENCH SKINNER, *Chairman*

P. ARNE HANSEN, *Vice-chairman*

H. J. WELSHIMER, *Secretary*

J. DOUGLAS REID, *Section Editor* (1956)

FRIDAY, MAY 8, 1953 – 10:00 A.M. – ROOM 434, MALLORY HALL

1. 10:00 The Use of Ovotran in Mite Infestations of Laboratory Animals.
James A. Hancock, Jr.; *Medical College of Virginia.*

2. 10:20 Action of Lysozyme on Several Cell Structures of *Bacillus megaterium.*
H. J. Welshimer; *Medical College of Virginia.*

3. 10:40 Cultivation of Leptospira in the Developing Chick Embryo.
Catherine M. Russell; *University of Virginia.*

FRIDAY, MAY 8, 1953 – 2:00 P.M.

2:00 Business Meeting.

4. 2:30 Primary Isolation of Johne's Bacillus *Mycobacterium paratuberculosis* from Bovine Intestinal Mucosa.
Robert H. Miller and P. Arne Hansen; *Department of Bacteriology and Live Stock Sanitary Service Laboratory, University of Maryland, College Park.*

5. 2:50 A Comparison of the Original Lowenstein Medium Against the Lowenstein-Jensen Modification in the Culture of *M. tuberculosis.*
John W. Pond and Geraldine Paul; *Richmond City Health Department and University of Richmond.*

6. 3:10 The Use of 24 Hour Egg Counts in *Paragonimus westermani* Infestations.
Michael Potter; *University of Virginia.*

Section of Biology

H. G. M. JOPSON, *Chairman*

ZOE WELLS CARROLL BLACK, *Vice-Chairman*

VERA B. REMSBURG, *Secretary*

ROBERT T. BRUMFIELD, *Section Editor* (1957)

FRIDAY, MAY 8, 1953 – 9:00 A.M. – ROOM 147, MALLORY HALL

9:00 Announcements, Committee Reports.

1. 9:10 The Taxonomic Significance of Megagametogenesis in *Tiarella cordifolia* L.
John M. Herr, Jr; *Washington and Lee University.*

2. 9:25 Discovery of *Forsstroemia ohioense* in Virginia.
Paul M. Patterson; *Hollins College.*

3. 9:35 A Simple Demonstration of the Effect of Heteroauxin on Plant Growth.
Robert T. Brumfield; *Longwood College.*

4. 9:45 The Sex Chromosomes of the Domestic Cat.
L. Husted, and George Walker; *University of Virginia.*

5. 10:00 A Study of the Cyclic Behavior of the Testis of *Cambarus longulus longulus* Girard With Notes on the Juvenile Males.
Vera B. Remsburg; *Longwood College.*

6. 10:15 Bernard Mikula's Collection of Mosses in Virginia.
Paul M. Patterson; *Hollins College.*

7. 10:25 Apparent Competition between Two Groups of Crayfishes in the Southeastern States.
Horton H. Hobbs, Jr.; *University of Virginia.*

8. 10:35 Observation on Testicular Behavior in the Crayfish, *Cambarus montanus acuminatus* Faxon.
Benjamin H. Word Jr.; *University of Virginia.*

11:00 Business Meeting.

FRIDAY, MAY 8 – 1:30 P.M.

9. 1:30 The Effect of Indole-3-Acetic Acid on Regeneration and Spore Germination in Mosses.
Suzanne Scollard; *Hollins College.*

10. 1:40 Aquatic Plant Life in Virginia.
A. B. Massey; *Virginia Polytechnic Institute.*

11. 1:55 The Nature of Rhabdites in *Stenostomum virginianum.*
E. W. Pullen; *University of Virginia.*

12. 2:05 The Spermatogenesis of Two Hematotaeniid Cestodes.
Lee T. Douglas; *Emory and Henry College.*

13. 2:20 Notes on the Occurrence of *Neoechinorhyncus cylindratus* in Fishes of Westhampton Lake.
Harry L. Holloway, Jr.; *University of Virginia.*

14. 2:30 Curvature in Timothy Roots Induced by Ultraviolet Radiaton.
Robert T. Brumfield; *Longwood College.*

3:30 Symposium on Resource-Use Education. OLD SCIENCE HALL.
Sponsored by the Resource-Use Education Committee of the Virginia Academy of Science.

MODERATOR: Alfred L. Wingo, *State Board of Education.*

PANEL: (Experts representing all of the resource agencies)

Prospective Participants:

1. I. T. Quinn, *Executive Director, Commission of Game and Inland Fisheries, Richmond, Va.*
2. S. W. Bondurant, *State Conservationist, Richmond, Va.*
3. George W. Dean, *State Forester, Va. Forest Service, Department of Conservation and Development, Charlottesville, Va.*
4. P. H. DeHart, *Assistant Director, Extension Service, V. P. I., Blacksburg, Va.*
5. J. L. McHugh, *Director, Virginia Fisheries Laboratory, Gloucester Point, Va.*
6. A. H. Anderson, *George Washington National Forest, Federal Building, Harrisonburg, Va.*
7. Charles Marsh, *William and Mary College, Williamsburg, Va.*
8. Ross H. Walker, *Mechanicsville, Va.*
9. Geo. W. Jeffers, *Biology Department, Longwood State Teachers College, Farmville, Va.*
10. Mrs. Elmira C. Maurice, *1208 W. 45 St., Richmond, Va.*

SATURDAY, MAY 9 — 8:30 A.M.

8:30 Field Trips.

Chemistry Section

HENRY LEIDHEISER, JR., *Chairman*
ROBERT C. KRUG, *Secretary*
CARL J. LIKES, *Section Editor*

FRIDAY, MAY 8 – 9:00 A.M. – ROOM 102, MAURY-BROOKE HALL

9:00 Introductory Remarks of the Chairman.

1. 9:15 The Phase Transformation of Cobalt as Observed on Single Crystals.
   Victor J. Kehrer, Jr. and Henry Leidheiser, Jr.; *Virginia Institute for Scientific Research.*

2. 9:30 Copper Chelates of Some β-Diketones.
   Connie Cole and Helen L. Whidden; *Randolph-Macon Woman's College.*

3. 9:45 An Investigation of the β-Amylase of Sweet Potatoes.
   Camilla Floyd and Laura Bliss; *Randolph-Macon Woman's College.*

4. 10:00 Chromatography in Quantitative Analytical Work.
   Margaret Fitzgerald and Helen L. Whidden; *Randolph-Macon Woman's College.*

5. 10:15 A Microcoulometric Method for the Measurement of the Relative Adsorption of Organic Substances on the Hydrogen Electrode.
   Thomas C. Franklin and Ray Sothern; *University of Richmond.*

6. 10:30 The Preparation of Some 9-(Dimethylphenyl)-1, 2-Benzanthracenes.
   Frank A. Vingiello and Alexej Borkovec; *Virginia Polytechnic Institute.*

7. 10:45 Mass Spectrometer Analysis of UO_2F_2 in UF_4.
   Russell Baldock, John R. Sites, L. O. Gilpatrick and Howard E. Carr; *Oak Ridge National Laboratory, Oak Ridge, Tenn.*

8. 11:00 The Use of an Anion Exchange Resin for the Isolation of Small Amounts of Zinc.
   Richard M. Rush; *Pratt Trace Analysis Laboratory, University of Virginia.*

9. 11:10 Guest Lecturer. Topic to be announced.

12:10 Business Meeting.

12:20 Recess for Lunch.

FRIDAY, MAY 8 – 2:00

10. 1:50 Dithizone Extraction of Sub-Microgram Quantities of Cobalt in the Presence of Ammonia.
John F. Williams; *Pratt Trace Analysis Laboratory, University of Virginia.*

11. 2:00 Further Study on the Synthesis of Anilino-Methanol.
Joseph E. Sanders, Jr. and Edgar V. Russell; *Virginia Polytechnic Institute.*

12. 2:15 Tetrazolium Chlorides.
A. Garnett Richardson and J. Stanton Pierce; *University of Richmond.*

13. 2:25 A Study of Methods Used for the Determination of Rare Earth Elements in Substances Containing a High Concentration of Calcium and Phosphorus.
Roger K. Hoover and J. B. Lucas; *Virginia Polytechnic Institute.*

14. 2:40 Reactivity of Primary Alkyl Bromides with Thiocyanate Ion.
Thomas I. Crowell; *University of Virginia.*

15. 2:55 Solubilities of Some Inorganic Salts in Hydrogen Peroxide – Water Mixtures.
John D. Floyd and Paul M. Gross, Jr.; *University of Virginia.*

16. 3:10 Electrodeposition of Aluminum.
Nelson F. Murphy; *Virginia Polytechnic Institute.*

17. 3:25 The Electric Dipole Moments of Some N-Monosubstituted Benzamides.
James E. Worsham, Jr. and Marcus E. Hobbs; *Duke University, Durham, N. C.*

18. 3:55 Powder Formation During the Catalytic Reaction of Hydrogen and Oxygen on a Copper Single Crystal.
Bruce Wagner, Jr.; *University of Virginia.*

19. 4:15 A Proposed Mechanism of Catalytic Rearrangement of Metal Surfaces.
R. E. Cunningham; *University of Virginia.*

20. 4:30 Some New Color Reactions for Trace Quantities of Boron.
Robert L. Grob; *Pratt Trace Analysis Laboratory, University of Virginia.*

21. 4:40 Some New Sensitive Color Reactions of Magnesium.
Charles K. Mann; *Pratt Trace Analysis Laboratory, University of Virginia.*

4:50 Adjourn.

SATURDAY, MAY 9 — 9:00 A.M.

22. 9:00 Some Errors in a Standard Gravimetric Procedure for the Determination of Sulfur in an Iron Ore.
William E. Whitehurst and Edgar V. Russell; *Virginia Polytechnic Institute.*

23. 9:15 Charles' and Boyle's Law Apparatus for General Chemistry.
N. W. Allen and H. Ritchey; *Virginia Military Institute.*

24. 9:30 A Mathematical Analysis of Errors Involved in Reducing Sedimentation Constants to Water at 20° C.
Carl J. Likes; *Virginia Institute for Scientific Research.*

25. 9:45 The Preparation of Some 9-(Dimethylphenyl)-Anthracenes.
Frank A. Vingiello and Edward Kramer; *Virginia Polytechnic Institute.*

27. 10:00 Trimethylchlorosilane Derivatives of Organolithium Compounds.
F. M. Braswell and H. Ritchey; *Virginia Military Institute.*

28. 10:15 A New Colorimetric Method for the Determination of Uranium.
John H. Yoe, Fritz Will, III and Robert A. Black; *Pratt Trace Analysis Laboratory, University of Virginia.*

29. 10:25 Controlled Atmospheres in Spectrochemical Analysis.
Ralph E. Thiers; *Pratt Trace Analysis Laboratory, University of Virginia.*

30. 10:40 Henry's Law Constants for Gases at High Temperatures.
Ray C. Elton and D. S. Davis; *Virginia Polytechnic Institute.*

31. 10:50 The Absolute Entropy of the Chloride Ion.
Elmer S. McKee; *Washington and Lee University.*

32. 11:05 The Change of Entropy of the Chloride Ion with Concentration and Type of Cation.
Elmer S. McKee and Bentz B. Howard, Jr.; *Washington and Lee University.*

33. 11:20 Distillation of Sea Water.
William H. Gaines and Frank C. Vilbrandt; *Virginia Polytechnic Institute.*

34. 11:35 Scientific Vocations — A Survey of Promotional Materials.
Lowell V. Heisey; *Bridgewater College.*

35. 11:45 Evidence for cis — trans Configuration and Effective Conjugations of α-Phenylchalcones.
W. Bruce Black and Robert E. Lutz; *University of Virginia.*

36. 12:00 Ring-Chain Tautomerism of Substituted cis-β-Aroylacrylic Acids.
James W. Rinker, Collin L. Browne and Robert E. Lutz; *University of Virginia.*

12:15 Adjourn.

Section of Education

JACK H. BOGER, *Chairman*

JOSEPH N. PAYNE, *Secretary*

FRANCIS G. LANKFORD, *Section Editor* (1957)

FRIDAY, MAY 8, 1953 – 9:00 A.M. – ROOM 454, MALLORY HALL

1. 9:00 A Study of Certain High School Graduates in Relation to their Elementary School Origins.
George G. Richards, Jr.; *Weller Baker School, Cambria.*

2. 9:30 Opportunities for Employment in Industry in the Norfolk Area of Virginia.
W. E. Lobeck; *Norfolk City Public Schools.*

3. 10:00 Some Principles, Procedures, and Problems Involved in Adjusting a College Curriculum to Meet the Challenge of Our Times.
Arnett G. Macklin; *Virginia State College.*

4. 10:30 A Study of the Academic Success of Virginia's College Freshmen Who Enrolled in the State's Institutions of Higher Learning During the Fall of 1948.
Alfred L. Wingo; *State Department of Education.*

5. 11:00 Academic Aptitude Testing of Freshmen at Longwood College.
M. Boyd Coyner; *Longwood College.*

6. 11:30 The Education of High School Science Teachers.
Percy H. Warren; *Madison College.*

7. 2:00 A Study of the Certification of Science Teachers in Virginia.
J. B. Chase; *University of Virginia.*

8. 2:30 Developing a Functional Program in Nursery School Education.
Alvia L. Bozeman; *Virginia State College.*

9. 3:00 Guidance Programs in Virginia Colleges.
W. D. Clague; *Bridgewater College.*

10. 3:30 Symposium on Resource-Use Education, sponsored by the Virginia Resource-Use Education Council.

Section of Engineering

VICTOR G. SZEBEHELY, *Chairman*

ROBERT W. TRUITT, *Secretary*

NELSON F. MURPHY, *Section Editor* (1953)

FRIDAY, MAY 8, 1953 – 9:00 A.M.

ROOM 105, NICHOLS ENGINEERING HALL

9:00 Announcements, Committee Reports.

1. 9:15 Engineering Aspects of Nuclear Energy.
   J. M. Morgan, Jr.; *Civil Engineering Department, Virginia Military Institute.*

2. 9:45 Analogies Based Upon the Two-Dimensional Poisson's Equation.
   James G. McGinley; *Applied Mechanics Department, Virginia Polytechnic Institute.*

3. 10:15 Compatibility of Highway Materials.
   Phillip L. Melville; *Council of Highway Investigation and Research, University of Virginia.*

4. 10:45 Model and Prototype Behavior of Engineering Structures.
   Dan H. Pletta; *Applied Mechanics Department, Virginia Polytechnic Institute.*

FRIDAY, MAY 8 – 2:00 P.M.

5. 2:00 A Survey of Various Methods of Analysis of Cantilever-Type Plates.
   William A. Nash; *Navy Department, David Taylor Model Basin.*

6. 2:45 Design, Construction and Calibration of a Small Supersonic Wind Tunnel.
   Fred W. Martin and Robert W. Truitt; *Aeronautical Engineering Department, Virginia Polytechnic Institute.*

7. 3:15 An Engineering Evaluation of the Continuity Method for Predicting the Form and Location of Detached Shock Waves for Two-Dimensional Flow.
   Perry W. Hanson; *Applied Mechanics Department, Virginia Polytechnic Institute.*

8. 3:45 The Two-Dimensional Subsonic Compressible Flow Over a Joukowsky Airfoil.
   Y. K. Pien and E. S. Cornette; *Applied Mechanics Department, Virginia Polytechnic Institute.*

9. 4:15 Aerodynamic Effects on a Body Immersed in a Non-Uniform Flow.
Joseph L. Hendricks; *Applied Mechanics Department, Virginia Polytechnic Institute.*

Business Meeting at the close of the afternoon session.

SATURDAY, MAY 9, 1953 – 9:00 A.M.

10. 9:00 Line Coordinate Chart for the Viscosity of Aqueous Glycerin.
Richard E. Herron and D. S. Davis; *Chemical Engineering Department, Virginia Polytechnic Institute.*

11. 9:30 The Effect of Operating Variables on Overhead Vapors and Residues from a Continuous Flash Distillation of Methanol-Water.
Charles E. Littlejohn and Frank C. Vilbrandt; *Chemical Engineering Department, Virginia Polytechnic Institute.*

12. 10:00 Design, Construction and Operation of a Continuous Pilot Plant Hypersorption Unit for Vapor Phase Separation of CS_2 and H_2S.
Seymour S. Stein and Frank C. Vilbrandt; *Chemical Engineering Department, Virginia Polytechnic Institute.*

13. 10:30 Operating and Design Variables in Continuous Liquid Thermal Diffusion.
C. Leo Kingrea and Frank C. Vilbrandt; *Chemical Engineering Department, Virginia Polytechnic Institute.*

14. 11:00 The Relation of Vessel Diameter to Several Properties of Fluidized Beds of Solid Particles.
John E. Lastovica, Jr. and Fred W. Bull; *Chemical Engineering Department, Virginia Polytechnic Institute.*

Section of Geology

RAYMOND S. EDMUNDSON, *Chairman*

WAYNE E. MOORE, *Vice Chairman*

WILLIAM T. PARROTT, *Secretary*

BYRON N. COOPER, *Section Editor* (1953)

FRIDAY, MAY 8 – 9:00 A.M. – ROOM 249, MALLORY HALL

9:00 Announcement, Committee Reports.

1. 9:10 Carolina Bays of the Coastal Plain of Virginia.
Allen Sinnott; *District Geologist Groundwater Branch, U.S. Geological Survey, Charlottesville.*

2. 9:15 New Concept of Appalachian Thrust Faults.
Wilbur A. Nelson; *University of Virginia.*

3. 9:25 The Influence of Meg. B-8 an East-West Zone of Crustal Mega-shearing.
B. Ashton Keith; *The Institute of Sciences, Washington, D. C.*

4. 9:40 The Stratigraphy of the Broadford Sandstone and Superjacent Marine Strata in Southwest Virginia.
Lynn Glover; *Virginia Polytechnic Institute.*

5. 9:55 Silurian Formations of Southwest Virginia.
Ralph L. Miller and Leonard D. Harris; *U. S. Geological Survey, Washington, D. C.*

6. 10:10 Evidence of Turbidity in the Lynchburg Formation.
Edwin O. Gooch; *Virginia Geological Survey, Charlottesville.*

7. 10:25 Mineralogical Studies of Sediments from Nottaway River, Virginia.
Alden M. Pitard, Daniel E. Popovich, William V. Trollinger, and Henry D. Wagener; *Washington and Lee University.* (Presented by Alden M. Pitard.)

8. 10:35 Summary of Stratigraphy of Virginia Coastal Plain.
D. J. Cederstrom; *United States Geological Survey, Charlottesville.*

9. 10:55 An Occurrence of Oolitic Chert in Rockbridge County, Virginia.
Perrin Walker; *University of Virginia.* (Introduced by R. S. Edmundson.)

10. 11:00 Residual Sands and Erosion Surfaces of Western Virginia.
W. D. Lowry; *Virginia Polytechnic Institute.*

11. 11:10 Mineralogical Studies of Sediments from Smith River.
Raymond F. Bee, Jefferson R. Kean, II, and George M. Young, *Washington and Lee University.* (Presented by George M. Young.)

12. 12:20 Lithologic Variations in the Beekmantown along Cub Run, Page County, Virginia.
Robert M. Cordova and George S. Meadors; *University of Virginia.* (Presented by George S. Meadors.) (Introduced by R. S. Edmundson.)

13. 11:30 Early Paleozoic Structure in Southwestern Virginia.
Wayne E. Moore; *Virginia Polytechnic Institute.*

11:40 Announcements — Adjourn for Lunch.

FRIDAY, MAY 8 — 1:30 P.M.

14. 1:30 Mineralogical Studies of Meherrin River, Virginia.
Ehrick K. Haight, James L. Hinkle, James C. Rich, and Jack A. Sites; *Washington and Lee University.* (Presented by James L. Hinkle.)

15. 1:40 Mineralogy of the Clay Fraction of some Piedmont Soils.
James L. Eades; *Council of Highway Research and Investigation, University of Virginia.*

16. 1:50 Paragenesis of Mineralization in the Climax Molybdenum Deposit Colorado.
Charles E. Sears, Jr.; *Virginia Polytechnic Institute.*

17. 2:05 Geologic Section Across Western Floyd County, Virginia.
Richard V. Dietrick; *Virginia Polytechnic Institute.*

18. 2:20 Geology of the Iron Deposits at the Riverside Mine Near Alvarado, Washington County, Virginia.
Byron N. Cooper and William E. Diggs; *Virginia Polytechnic Institute.* (Presented by William E. Diggs.)

19. 2:40 Trilobites from the Lower Champlainian Formations in the Appalachian Valley.
Byron N. Cooper; *Virginia Polytechnic Institute.*

20. 2:55 Outline of the Geology of Poor Mountain, Roanoke and Floyd Counties, Virginia.
T. E. Shufflebarger; *Virginia Polytechnic Institute.*

21. 3:10 Subsurface Reconnaissance by the Electrical Resistivity Method.
John P. Meador; *Virginia Department of Highways, Richmond.*

21. 3:25 Some Current Activities and Projects of the State Geological Survey.
William McGill; *Virginia Geological Survey.*

3:40 Business Meeting.

SATURDAY, MAY 9 — 8:00 A.M.

8:00 A.M. Mineral Collecting Field Trip at Irish Creek and vicinity — Place of assembling and details of trip to be announced at the meeting.

Section of Medical Sciences

E. G. HUF, *Chairman*

D. R. H. GOURLEY, *Secretary*

WILLIAM BICKERS, *Section Editor* (1953)

FRIDAY, MAY 8 – 10:30 A.M. – ROOM 442, MALLORY HALL

1. Effect of Insulin on the Oxygen Consumption of Intact Skeletal Muscle *in vitro*.
   D. R. H. Gourley; *University of Virginia Medical School.*
2. The Influence of Low Protein Diet on the Distribution of Amino Acid Oxidases in Rats.
   C. Hoch-Ligeti; *University of Virginia Medical School.*
3. Autonomic Responses from the Cortex of the Dog.
   Herbert G. Langford; *Medical College of Virginia.*
4. The Role of Epinephrine in Ether Hyperglycemia.
   D. T. Watts; *University of Virginia Medical School.*
5. Synthesis and Metabolism of N^{15}-labeled Ethanolamine.
   Lynn D. Abbott, Jr. and Jack D. Klingman; *Medical College of Virginia.*
6. The Ionization Constants of Thyroxine and Related Compounds.
   C. L. Gemmill; *University of Virginia Medical School.*
7. Effects of ATP Complexes on P^{32} Uptake by Rabbit Erythrocytes.
   H. Jonas; *University of Virginia Medical School.*
8. Effect of the Intravenous Administration of Paritol-C on the Serum Lipids of Hypercholesterolemic Rabbits.
   J. C. Forbes and Olga Petterson; *Medical College of Virginia.*
9. A Histochemical Study of the Lipids of the Corpus Luteum of Pregnancy in the Water Snake, *Natrix sipedon sipedon.*
   D. E. Bragdon; *University of Virginia Medical School.*
10. Effect of the Repeated Administration of Alcohol on Guinea Pigs on a Scorbutogenic Diet.
    J. C. Forbes and G. M. Duncan; *Medical College of Virginia and Division of Alcohol Studies and Rehabilitation, Department of Health, Commonwealth of Virginia, Richmond.*
11. The Possible Role of Psychological Factors in Causalgea.
    Murray G. Mitts; *Medical College of Virginia.*

Section of Psychology

S. B. WILLIAMS, *Chairman*

L. S. REID, *Secretary-Treasurer*

W. M. HINTON, *Executive Committeeman*

RICHARD H. HENNEMAN, *Section Editor* (1954)

FRIDAY, MAY 8 – 9:00 A.M. – ROOM 18, SCOTT-SHIPP HALL

1. 9:00 The Relative Effectiveness of Auditory and Visual Messages under Conditions of Noise.
   James G. Holland; *University of Virginia.*
2. 9:15 The Course of Cutaneous Adaptation to Audio-frequency Current.
   Andrew W. Gottschall; *University of Virginia.*
3. 9:30 Stability of Color Preference.
   Walter A. Woods; *Richmond Professional Institute.*
4. 9:45 Nonreinforced Training in the T-maze.
   Melvin Frietag; *University of Virginia.*
5. 10:00 An Experimental Test of the Estes Versus the Bush and Mostellar Theories of Learning.
   Beth Forester and Burton P. Wolin; *College of William and Mary.*

   10:15 Fifteen Minute Intermission . . .

6. 10:30 The Use of Continuous Addition Technique in Psychological Diagnosis.
   V. J. Bielianskas; *Richmond Professional Institute.*
7. 10:45 Serial Effects as a Function of Inter-stimulus Interval.
   Willard F. Day; *University of Virginia.*
8. 11:00 The Development of Syllogistic Reasoning in Children Five Through Eleven Years of Age.
   Charles A. Peachee, Jr.; *Central State Hospital.*
9. 11:15 Tactual Apparent Movement.
   Raymond C. Bice; *University of Virginia.*
10. 11:30 Sweetness and Food Consumption.
    William Wagman; *College of William and Mary.*
11. 11:45 A Study of Voice as Related to Personality Traits.
    Cora Lynn Chaffee; *Richmond Professional Institute.*

FRIDAY, MAY 8 – 2:00 P.M.

2:00 Business Meeting of Psychology Section.

12. 3:15 Physical Dimensions Related to the Perception of Mechanical Vibration.
Carl E. Sherrick; *University of Virginia.*

13. 3:30 A Study of Anxiety in the Minnesota Multiphasic Personality Inventory.
William E. Cook; *Richmond Professional Institute.*

14. 3:45 A New Short-cut Method of Psychotherapy for Psychoses.
John A. Blake; *Central State Hospital.*

Section of Science Teachers

THOMAS H. CRISTIE, *Chairman*

CAROLINE GAMBRILL, *Chairman-Elect*

L. W. JARMAN, *Section Editor* (1954)

FRIDAY, MAY 8 — 9:00 A.M .— ROOM 252, MALLORY HALL

9:00 Appointment of Committees and Announcements.

1. 9:10 Embedding Biological Specimens in Plastics.
Howard H. Edgerton; *Carolina Biological Supply Company.*

2. 9:40 Preparation for College Chemistry.
W. G. Guy; *William and Mary College.*

3. 10:10 Atomic Energy in High School Science Courses.
C. E. Savage; *Augusta Military Academy.*

10:40 Election of Officers.

4. 10:55 Use Techniques in Elementary Science.
Madison College.

5. 11:25 Discussion on the Use of Plastics in Science Teaching.
Howard H. Edgerton; *Carolina Biological Supply Company.*

6. 11:50 Evaluation of the Program.

FRIDAY, MAY 8 — 3:30 P.M. — OLD SCIENCE HALL

3:30 Symposium on Research-Use Education.
Sponsored by the Virginia Resource-Use Education Council.

Section of Statistics

A. M. MYSTER, *Chairman*

G. W. SUTER, *Vice-Chairman*

C. Y. KRAMER, *Secretary*

W. A. HENDRICKS, *Section Editor* (1954)

FRIDAY, MAY 8 – 10:00 A.M. – ROOM 237, MALLORY HALL

10:00 Introductory Remarks of the Chairman.

1. 10:10 On the Analysis of Variance of a Multiway Classification with Unequal Sub-Class Numbers.
   C. Y. Kramer and D. B. Duncan, *Virginia Polytechnic Institute.*
2. 10:30 Some Aspects of the Comparisons of Experiments. (Invited paper.)
   David Blackwell; *Howard University.* (Introduced by Boyd Harshbarger.)
3. 11:30 Business Meeting.
4. 12:30 Statistics Luncheon.

FRIDAY, MAY 8 – 2:00 P.M.

5. 2:00 Statistics in Biology. (Invited paper).
   Clifford J. Maloney; *Chemical Corps Biological Laboratories.* (Introduced by David B. Duncan.)
6. 3:00 Paired Comparisons in a Lattice Design.
   Boyd Harshbarger; *Virginia Polytechnic Institute.*
7. 3:20 A New Multiple Range Test for Differences Between Treatments in an Analysis of Variance.
   D. B. Duncan; *Virginia Polytechnic Institute.*
8. 3:40 On the Operation of the Univac.
   Joseph V. Natrella, *U. S. Air Force.*
9. 4:05 On the Non-negative Solution of a Linear Form Subject to Linear Constraints.
   Lt. James V. Kelley; *U. S. Air Force.*

SATURDAY, MAY 9 – 9:00 A.M.

10. 9:00 A Significance Test for Differences Between Treatments in Certain Incomplete Block Designs.
    Edwin Bleicher; *Virginia Polytechnic Institute.*

11. 9:20 Some Further Extensions of the Rank Analysis of Incomplete Block Designs.
R. A. Bradley; *Virginia Polytechnic Institute.*

12. 9:40 Further Extensions of the Multiple Comparisons Tests to Incomplete Block Designs.
Paul Sanders; *Virginia Polytechnic Institute.*

13. 10:00 A Modification of the Aitken-Neville Interpolation Formulae.
M. C. K. Tweedie; *Virginia Polytechnic Institute.*

14. 10:20 The Techniques Used in Field Testing the Compound, Dishwashing, Hand, T-52-1.
Elie Weeks; *Quartermaster Board.*

15. 10:40 Use of I. B. M. Equipment in Statistics.
R. G. Cornell; *Virginia Polytechnic Institute.*

16. 11:00 Use of I. B. M. Equipment in the Analysis of Variance.
R. M. Abelson; *Virginia Polytechnic Institute.*

17. 11:20 Certain Percentage Points of the Distribution of the Range of Large Samples.
W. H. Beyer; *Virginia Polytechnic Institute.*

18. 11:40 Confidence Intervals for Differences Between Treatments in an Analysis of Variance.
Robert Bonner; *Virginia Polytechnic Institute.*